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USING GRAPHITE FILAMENT COMPOSITION AS A DIE MATERIAL

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OCTOBER 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Technological advances in graphite filament-reinforced compounds have provided a material adaptable for use in propellant extrusion operations. Two graphite composite formulations were selected for evaluation. Each contained 30 percent graphite and 15 percent Teflon, with the remaining constituent being nylon and polyphenylene sulfide (PPS), respectively.

Dies were fabricated from the above materials and were compared with Delrin dies, currently used in propellant manufacturing operations, to establish

All propellant manufactured throughout the evaluation met the established quality parameters. No quality or processing difficulty that could be attributed to the introduction of the special die agates was reported.

The stainless steel, Teflon-coated and the graphite/Teflon/PPS dies were superior to the other two dies in maintaining dimensional stability. The graphite/Teflon/PPS die was subject to damage during removal and cleaning operations and requires care when being handled during these operations.

An economic evaluation indicated that substantial cost savings would accrue if the graphite/Teflon/PPS die is selected for production use.

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I. INTRODUCTION

The purpose of this project was to establish the feasibility of using die agates fabricated from molded graphite composites for the extrusion of solvent-type cannon propellants to reduce initial fabrication costs, increase the service life of the parts, and reduce the time required to procure sufficient components to support the mobilization schedule in the event of a national emergency.

The graphite composite formulations selected for use in this evaluation were composed of the following ingredients:

1. 30 percent graphite, 15 percent Teflon, 55 percent nylon.

2. 30 percent graphite, 15 percent Teflon, 55 percent PPS.

The graphite was Hercules AS material (reference Hercules Incorporated Product Data Sheet No. 831-1) manufactured at the Bacchus Works of Hercules Incorporated. The nylon was Nylon 6/6; the polyphenylene sulfide resin (Ryton) was manufactured by the Phillips Chemical Company, Division of the Phillips Petroleum Company.

A total of 60 agate blanks of each of the two graphite composite formulations were procured from Keithly Custom Molding Division, Cleveland, Ohio, (now identified as the Kenyon Materials Division of Lord Corporation). The die agate blanks were molded slightly oversize to assure meeting the minimum die agate sizes desired at RAAP and were machined at RAAP to the desired dimensions.

Concurrently, 30 Delrin die agates with stainless steel outer jackets were also prepared for comparison. An additional die agate was also introduced for comparison which was assumed to be more stable than the Delrin die, and also was judged to have some production potential, especially for use in standard production items. This die agate was fabricated from stainless steel at RAAP and sent to General Magnaplate Corporation, Linden, New Jersey, for the application of a 0.019 mm (0.00075 in) Teflon coating on the wear surfaces of the agate.

The die agates selected for this study were used to equip four regular production 305 mm (12 in) solvent-type extrusion presses, each containing one of the agate types, for evaluation in the manufacture of M30 propellant for the 105 mm, M490 and M456A1 cartridge systems. The die configuration was that currently in use for this propellant item with nominal dimensions of 8.865 mm (0.349 in) inside diameter (ID) agate, 4.801 mm (0.189 in) pin circle, and containing seven 0.686 mm (0.027 in) pins. This propellant item was selected for the evaluation because it was the major production item forecast to be in production at the time the die agates would be ready for production use. For a variety of reasons, this did not materialize. Runs of short duration were the case, thus making coordination in the production

operations more difficult and extended the total time to acquire adequate data. However, the delays caused by the short production runs may have permitted certain aberrations in the behavior of two of the die types (Delrin and graphite/Teflon/nylon) to become more visible and thus produced an added benefit from this evaluation.

II. INVESTIGATIVE PROGRAM

M30 propellant for Cartridges, TP-T, M490, and HEAT, M456A1 for the 1C5 mm gun was selected for the die agate evaluation since this item was the major item on the production schedule during the period of evaluation and was deemed to be produced in sufficient quantity to permit acquisition of adequate information. The die agate for the granulation of this item presently required an agate assembly consisting of a stainless steel sleeve encasing a machined Delrin insert. Figure 1 is a sketch of the Delrin agate design as used in production 305 mm (12 in) presses to granulate this propellant item and was selected as the base die agate for comparison with the graphite dies. At the outset of this study, an evaluation program was designed to obtain wear and failure data on the two types of graphite molded dies selected for this evaluation and for comparison with the steel-jacketed Delrin insert dies currently being used in propellant manufacturing operations. Since data obtained from production records indicated Delrin agates showed some dimensional instability, an attempt was made to find a more dimensionally stable die agate for comparison purposes. A stainless steel agate was selected, prepared in the RAAP shops and sent to the General Magnaplate Corporation, Linden, New Jersey, for the application of a thin layer of Teflon on the extrusion surfaces of the agate, using a company proprietary process identified as the Nedox process. In this process, a hard surface consisting of chrome-nickel alloy is electro-deposited on the metal surface of the die agate and the micropores of the metal are later enlarged to accept a controlled infusion of polytetrafluoroethylene (Teflon) to give the desired coating thickness. Further information on this coating process is on file at RAAP.

III. DIE EVALUATION STUDY

A. Preparation of Die Agates and Discussion of Data

The mold for the graphite composite die agate blanks was made by Keithley Custom Molding Division and a total of 120 agate assemblies (60 from each of the two selected graphite formulations) molded. These assemblies were molded oversize so that they could be machined to size, although an attempt was made to determine the vendor's capability to control dimensions of the finished agates so that future parts could be procured more nearly to final tolerances.

Upon receipt and prior to final machining, measurements from representative samples of agate blanks were made for shoulder outside diameter (OD), shoulder thickness, length, barrel OD at the base, barrel OD

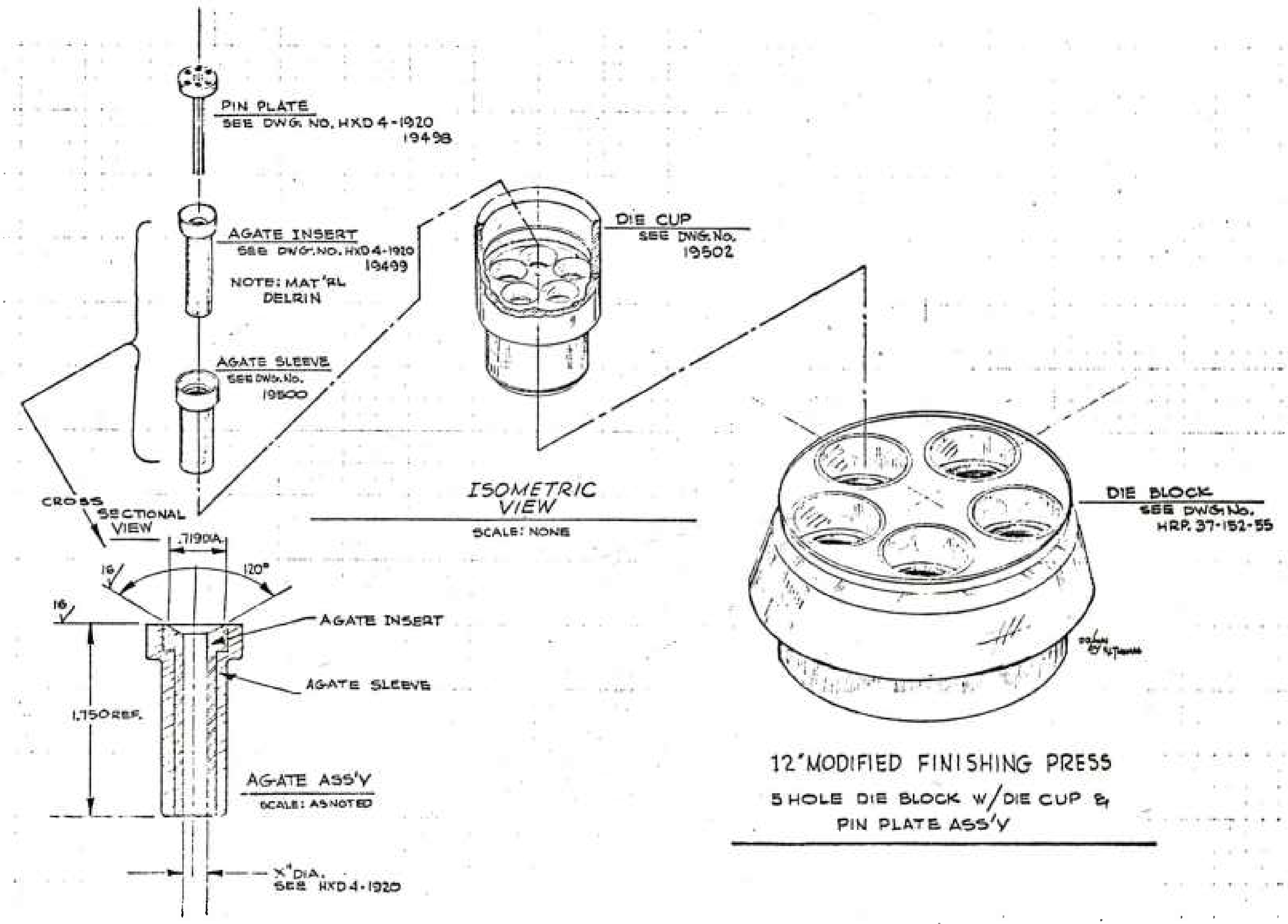

Figure 1. Sketch of Delrin die used in manufacture of M30 propellant.

under the shoulder, ID at the bottom, ID at the base, and concentricity. These measurements were made to determine the dimensional tolerances that were maintained during molding, a summary of which is presented in Table 1.

Also included in Table 1 are the results of statistical analyses of these measurements, including the capability of the vendor to predictably meet the drawing tolerances. These data show that the vendor's process can meet the finished parts dimensions for the shoulder OD and thickness but did not have sufficient process control or the correct mold tolerances to meet agate drawing tolerances for all dimensions. These data will permit minor adjustments to be made in the vendor's process to enable the agate blanks to more closely fit the final design dimensions. Each of the agate blanks required minimal machining, thus a slight deviation in certain agate dimensions would not appear to be prohibitive. It was concluded from these data that the most logical method of procurement of these parts in the future would be to work closely with the vendor to make refinements in the mold design or molding process to maintain ODs and length tolerances only. The agate approach angle and ID surfaces would then be machined at RAAP to fit the particular propellant being manufactured. This would tend to give maximum flexibility and would enable a specified die agate blank to be inexpensively tailored to suit a variety of propellant die agate requirements. Photographs of a representative sample of the two types of graphite composition die agates showing a view of both the as-received agate blank as well as the finished agate configuration following machining at RAAP are presented as Figures 2 and 3. Figure 2 is the graphite/Teflon/PPS composition agate and Figure 3 is the graphite/Teflon/nylon composition agate.

Samples of both graphite agate compositions were tested and found to be compatible.

After machining, 30 of each of the two types of graphite composition die agates, 30 Delrin agates fabricated in the RAAP shops as the standard, and 30 of the Teflon-coated steel agates, were submitted to Quality Control for final inspection prior to their being introduced into the production cycle. Table 2 presents the data obtained from these inspections for the two graphite composition agates and the Delrin type agates, whereas Table 3 presents the data obtained from the inspection of the Teflon-coated steel agates. As can be seen from these data, all agates met the desired requirements and were deemed to be totally acceptable dimensionally for this study.

In Table 3 the measurements of the Teflon-coated agates, both prior to and after coating, are given to determine the thickness of the Teflon coating obtained and to evaluate the vendor's capability to control the coating thickness on similar applications. A review of these data, obtained from the agate measurements, as presented in Table 3 shows a coating thickness of 0.019 mm (0.00075 in), with a standard deviation of

TABLE 1A. GRAPHITE MOLD DATA IN METRIC UNITS (Mold Dimensional Capability - Dimensions in mm)

	Shoulder			O.D. of Barrel		I.D. of Agate		T.I.R.	
	O.D.	Thickness	Length	Base	Shoulder	Bottom	Shoulder	Shoulder	Base
Graphite-TFE-Nylon									
Average, $\overline{X}_{10}$	22.34	6.48	44.44	16.06	15.94	8.56	8.70	0.350	0.076
Std. Dev., σ	0.016	0.025	0.067	0.044	0.014	0.045	0.038	0.023	0.018
$\overline{X} + 3\sigma$	22.31	6.56	44.64	16.19	15.98	8.69	8.81	0.356	0.127
$\overline{X} - 3\sigma$	22.21	6.41	44.24	15.92	15.90	8.42	8.59	0.229	0
σ Range	0.10	0.15	0.40	0.27	0.08	0.27	0.22	0.127	0.127
Graphite-TFE-PPS									
Average, $\overline{X}_{10}$	22.35	6.46	44.21	16.13	16.05	8.55	8.64	0.229	0.051
Std. Dev., σ	0	0.030	0.042	0.023	0.056	0.018	0	0.013	0.015
$\overline{X} + 3\sigma$	22.35	6.56	44.34	16.20	16.08	8.60	8.64	0.28	0.10
$\overline{X} - 3\sigma$	22.35	6.38	44.08	16.06	16.01	8.50	8.64	0.18	0
σ Range	0	0.18	0.26	0.14	0.07	0.11	0	0.10	0.10
Drwg. Tolerance (Die Final Dim.)	+0 -0.127	+0.127 -0.127	+0.127 -0.127	+0 -0.013	+0 -0.013	+0.025 -0.025	+0.025 -0.025	⊙ A 0.025	⊙ 0.025
Best Tol. Possible	±0.048	±0.089	±0.201	±0.132	±0.041	±0.201	±0.111	±0.064	0.064

TABLE 1B. GRAPHITE MOLD DATA IN CONVENTIONAL UNITS (Mold Dimensional Capability - Dimensions in inches)

	Shoulder			O.D. of Barrel		I.D. of Agate		T.I.R.	
	O.D.	Thickness	Length	Base	Shoulder	Bottom	Shoulder	Shoulder	Base
Graphite-TFE-Nylon									
Average, $\overline{X}_{10}$	0.8765	0.2552	1.7497	0.6321	0.6276	0.3369	0.3425	0.012	0.003
Std. Dev., σ	0.00063	0.00100	0.00265	0.00173	0.00055	0.00179	0.00148	0.0009	0.0007
$\overline{X} + 3\sigma$	0.8784	0.2582	1.7576	0.6373	0.6293	0.3423	0.3470	0.014	0.005
$\overline{X} - 3\sigma$	0.8746	0.2522	1.7417	0.6269	0.6260	0.3315	0.3381	0.009	0.000
σ Range	0.0038	0.0060	0.0159	0.0104	0.0033	0.0108	0.0089	0.005	0.005
Graphite-TFE-PPS									
Average, $\overline{X}_{10}$	0.8800	0.2545	1.7406	0.6349	0.6317	0.3366	0.3403	0.009	0.002
Std. Dev., σ	0.00000	0.00118	0.00167	0.00089	0.00220	0.00071	0.00000	0.0005	0.0006
$\overline{X} + 3\sigma$	0.8800	0.2581	1.7456	0.6376	0.6331	0.3387	0.3403	0.011	0.004
$\overline{X} - 3\sigma$	0.8800	0.2510	1.7356	0.6322	0.6304	0.3345	0.3403	0.007	0.000
σ Range	0	0.0071	0.0100	0.0054	0.0027	0.0042	0	0.004	0.004
Drwg. Tolerance (Die Final Dim.)	+0.000 -0.005	±0.005	±0.005	+0.0000 -0.0005	+0.0000 -0.0005	±0.001	±0.001	⊙ 0.001 A	⊙ 0.001
Best Tol. Possible	±0.0019	±0.0035	±0.0079	±0.0052	±0.0016	±0.0052	±0.0044	±0.0025	±0.0025

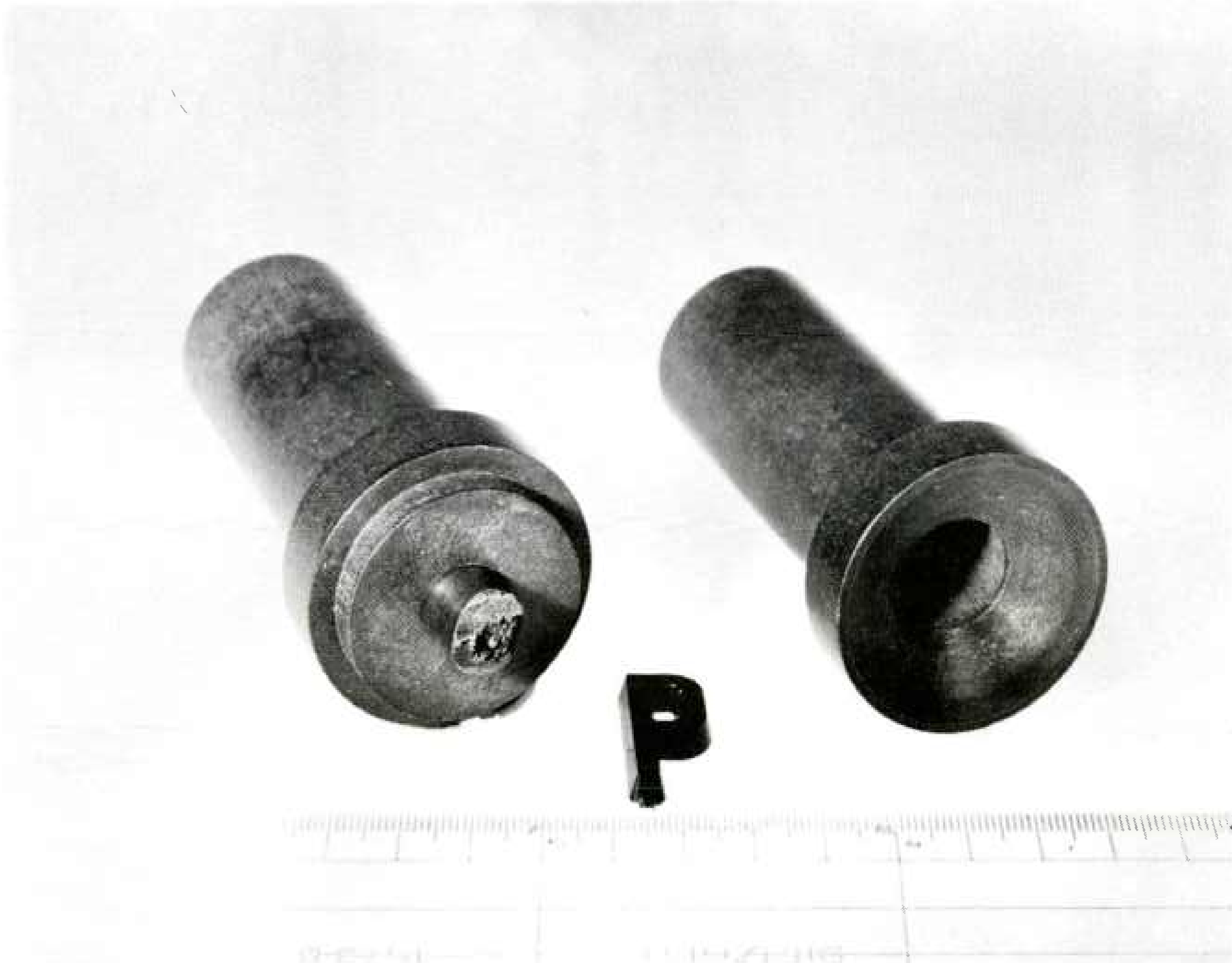

Figure 2. Graphite/Teflon/PPS die agate blank as received and following machining at RAAP.

Figure 3. Graphite/Teflon/nylon die agate blank as received and following machining at RAAP.

TABLE 2A. ORIGINAL PHYSICAL MEASUREMENT DATA OF DELRIN AND GRAPHITE COMPOSITE DIE AGATES, METRIC UNITS

Agate	Agate ID, mm			Agate Approach Angle, rad			ID Top of Agate Approach, mm			Radius, Agate Approach, rad		
No.	Delrin	G/TFE/PPS	G/TFE/N	Delrin	G/TFE/PPS	G/TFE/N	Delrin	G/TFE/PPS	G/TFE/N	Delrin	G/TFE/PPS	G/TFE/N
1	8.870	8.865	8.860									
2	8.872	8.872	8.857									
3	8.865	8.860	8.857									
4	8.865	8.867	8.860									
5	8.870	8.860	8.862	2.086	2.128	2.101	20.890	20.320	20.371	0	0	0
6	8.870	8.860	8.862									
7	8.865	8.860	8.865									
8	8.865	8.860	8.872									
9	8.867	8.860	8.857									
10	8.867	8.862	8.857	2.083	2.128	2.098	20.955	20.295	20.371	0	0	0
11	8.865	8.857	8.852									
12	8.870	8.862	8.857									
13	8.867	8.857	8.860									
14	8.865	8.880	8.867									
15	8.870	8.857	8.857	2.100	2.127	2.102	20.890	20.549	20.371	0	0	0
16	8.872	8.860	8.865									
17	8.865	8.865	8.870									
18	8.867	8.852	8.867									
19	8.865	8.872	8.854									
20	8.865	8.867	8.860	2.093	2.127	2.104	20.930	20.574	20.371	0	0	0
21	8.865	8.862	8.865									
22	8.865	8.857	8.862									
23	8.870	8.860	8.860									
24	8.867	8.857	8.867									
25	8.865	8.862	8.857									
26	8.865	8.870	8.862									
27	8.862	8.875	8.857									
28	8.867	8.860	8.862									
29	8.860	8.887	8.862									
30	8.867	8.857	8.860									
$\overline{X}_{30}$	8.866	8.863	8.861									
σ	0.00279	0.00762	0.00457									

TABLE 2B. ORIGINAL PHYSICAL MEASUREMENT DATA ON DELRIN AND GRAPHITE COMPOSITE DIE AGATES, CONVENTIONAL UNITS

Agate No.	Agate ID, inches			Agate Approach Angle, degrees/minutes			ID Top of Agate Approach, inches			Radius, Agate Approach, inches		
	Delrin	G/TFE/PPS	G/TFE/N	Delrin	G/TFE/PPS	G/TFE/N	Delrin	G/TFE/PPS	G/TFE/N	Delrin	G/TFE/PPS	G/TFE/N
1	0.3492	0.3490	0.3488									
2	0.3493	0.3493	0.3487									
3	0.3490	0.3488	0.3487									
4	0.3490	0.3491	0.3488									
5	0.3492	0.3488	0.3489	119/16	121/40	120/9	0.826	0.800	0.802	0	0	0
6	0.3492	0.3488	0.3489									
7	0.3490	0.3488	0.3490									
8	0.3490	0.3488	0.3493									
9	0.3491	0.3488	0.3487									
10	0.3491	0.3489	0.3487	119/7	121/41	119/57	0.825	0.799	0.802	0	0	0
11	0.3490	0.3487	0.3485									
12	0.3492	0.3489	0.3487									
13	0.3491	0.3487	0.3488									
14	0.3490	0.3496	0.3491									
15	0.3492	0.3487	0.3487	120/5	121/37	120/10	0.826	0.809	0.802	0	0	0
16	0.3493	0.3488	0.3490									
17	0.3490	0.3490	0.3492									
18	0.3491	0.3485	0.3491									
19	0.3490	0.3493	0.3486									
20	0.3490	0.3491	0.3488	119/41	121/37	120/16	0.824	0.810	0.802	0	0	0
21	0.3490	0.3489	0.3490									
22	0.3490	0.3487	0.3489									
23	0.3492	0.3488	0.3488									
24	0.3491	0.3487	0.3491									
25	0.3490	0.3489	0.3487									
26	0.3490	0.3492	0.3489									
27	0.3489	0.3494	0.3487									
28	0.3491	0.3488	0.3489									
29	0.3488	0.3499	0.3489									
30	0.3491	0.3487	0.3488									
$\overline{X}_{30}$	0.34907	0.34895	0.348857									
σ	0.00011	0.00030	0.00018									

TABLE 3A. ORIGINAL PHYSICAL MEASUREMENT DATA OF TEFLON-COATED STEEL DIE AGATES, METRIC UNITS

Agate No.	Agate, I.D., mm Before Coating	After Coating	Coating Thickness, Calculated, mm	Coating Thickness, Calculated, Average, mm	Agate Approach Dimensions Angle, rad	Top I.D., mm	Radius, rad
1	8.903	8.867	0.036	0.0180			
2	8.905	8.872	0.035	0.0175			
3	8.903	8.867	0.036	0.0180			
4	8.910	8.865	0.045	0.0225			
5	8.905	8.867	0.038	0.0190	2.105	18.161	0
6	8.905	8.872	0.033	0.0165			
7	8.910	8.872	0.038	0.0190			
8	8.915	8.865	0.050	0.0250			
9	8.903	8.867	0.036	0.0180			
10	8.903	8.865	0.038	0.0190	2.104	18.059	0
11	8.903	8.867	0.036	0.0180			
12	8.905	8.867	0.038	0.0190			
13	8.910	8.865	0.045	0.0225			
14	8.905	8.870	0.035	0.0175			
15	8.905	8.867	0.038	0.0190	2.123	18.212	0
16	8.905	8.865	0.040	0.0200			
17	8.908	8.870	0.038	0.0190			
18	8.905	8.865	0.040	0.0200			
19	8.905	8.865	0.040	0.0200			
20	8.903	8.865	0.038	0.0190	2.082	18.212	0
21	8.903	8.867	0.036	0.0180			
22	8.908	8.865	0.043	0.0215			
23	8.903	8.865	0.038	0.0190			
24	8.903	8.867	0.036	0.0180			
25	8.903	8.872	0.031	0.0155			
26	8.903	8.870	0.033	0.0165			
27	8.905	8.865	0.040	0.0200			
28	8.905	8.867	0.038	0.0190			
29	8.903	8.865	0.038	0.0190			
30	8.905	8.867	0.038	0.0190			
$\overline{X}_{30}$	8.90499	8.86706	0.0382	0.0191			
σ	0.0044	0.0026	0.0042	0.0021			

TABLE 3B. ORIGINAL PHYSICAL MEASUREMENT DATA ON TEFLON-COATED STEEL DIE AGATES, CONVENTIONAL UNITS

	Agate I.D., inch		Coating Thickness,	Coating Thickness,	Agate Approach Dimensions		
Agate No.	Before Coating	After Coating	Calculated, inch	Calculated, Average, inch	Angle, °/min.	Top I.D., inch	Radius, degrees
1	0.3505	0.3491	0.0014	0.0007			
2	0.3506	0.3493	0.0013	0.00065			
3	0.3505	0.3491	0.0014	0.0007			
4	0.3508	0.3490	0.0018	0.0009			
5	0.3506	0.3491	0.0015	0.00075	120/37	0.715	0
6	0.3506	0.3493	0.0013	0.00065			
7	0.3508	0.3493	0.0015	0.00075			
8	0.3510	0.3490	0.0020	0.0010			
9	0.3505	0.3491	0.0014	0.0007			
10	0.3505	0.3490	0.0015	0.0075	120/35	0.711	0
11	0.3505	0.3491	0.0014	0.0007			
12	0.3506	0.3491	0.0015	0.00075			
13	0.3508	0.3490	0.0018	0.0009			
14	0.3506	0.3492	0.0014	0.0007			
15	0.3506	0.3491	0.0015	0.00075	121/37	0.717	0
16	0.3506	0.3490	0.0016	0.0008			
17	0.3507	0.3492	0.0015	0.00075			
18	0.3506	0.3490	0.0016	0.0008			
19	0.3506	0.3490	0.0016	0.0008			
20	0.3505	0.3490	0.0015	0.00075	119/17	0.717	0
21	0.3505	0.3491	0.0014	0.0007			
22	0.3507	0.3490	0.0017	0.00085			
23	0.3505	0.3490	0.0015	0.00075			
24	0.3505	0.3491	0.0014	0.0007			
25	0.3505	0.3493	0.0012	0.0006			
26	0.3505	0.3492	0.0013	0.00065			
27	0.3506	0.3490	0.0016	0.0008			
28	0.3506	0.3491	0.0015	0.00075			
29	0.3505	0.3490	0.0015	0.00075			
30	0.3506	0.3491	0.0015	0.00075			
$\overline{X}_{30}$	0.35059	0.3490967	0.0015033	0.0007517			
σ	0.0001732	0.00010334	0.000165	0.00008251			

0.002 mm (0.00008 in) and resulted in an agate ID of 8.867 mm (0.3491 in) against a desired dimension of 8.865 mm (0.3490 in). These data indicate that the Nedox Teflon coating process utilized by the General Magnaplate Corporation is both predictable and reproducible and could potentially have other desirable applications at RAAP.

Photographs were obtained of representative samples of each of the four die agate types at the beginning of the evaluation (Figures 4 through 7) in order that the effects of production wear or damage resulting from usage could be visually recorded and made a part of this project evaluation.

B. Propellant Manufacture and Die Agate Evaluation

At the outset of this evaluation, four production 305 mm (12 in) presses were randomly selected out of the eight operating presses in one operating press building with each press holding agates with a different type of material. The remaining presses utilized Delrin agates and operated as required to support the product flow. A total of 30 die agates having 8.865 mm (0.349 in) ID, 4.801 mm (0.189 in) pin circle, and 0.686 mm (0.027 in) pins per agate type were prepared and set up in standard 305 mm (12 in) press die holders containing five agates per holder and were utilized in granulating M30 propellant. Six die holders were thus made available to the operating department so that a spare holder, in addition to the five in the press, would be available. This enabled the operating department to keep the presses containing the evaluation die agates in production even when normal operating problems caused the removal of a particular die holder for die agate cleaning. The die holders were rotated from week-to-week to permit an equal evaluation of all the agates. During periods of reduced product flow, propellant was extruded through the evaluation agates, thus permitting the maximum product throughput for the agates being evaluated. During the course of the evaluation, presses in both operational press houses were utilized, thus the die agates were introduced to all normal operating conditions.

The die agates which were identified with an etched serial number for positive identification were installed in presses according to the following test plan:

Press	Agate Material	Agate Serial No.
1	Teflon-coated steel (Nedox process)	1 through 30
2	Delrin insert in steel	101 through 130
3	30% graphite fiber 15% Teflon 55% PPS	201 through 230
4	30% graphite fiber 15% Teflon 55% nylon	301 through 330

Figure 4. Teflon-coated steel die agates ready for production use,

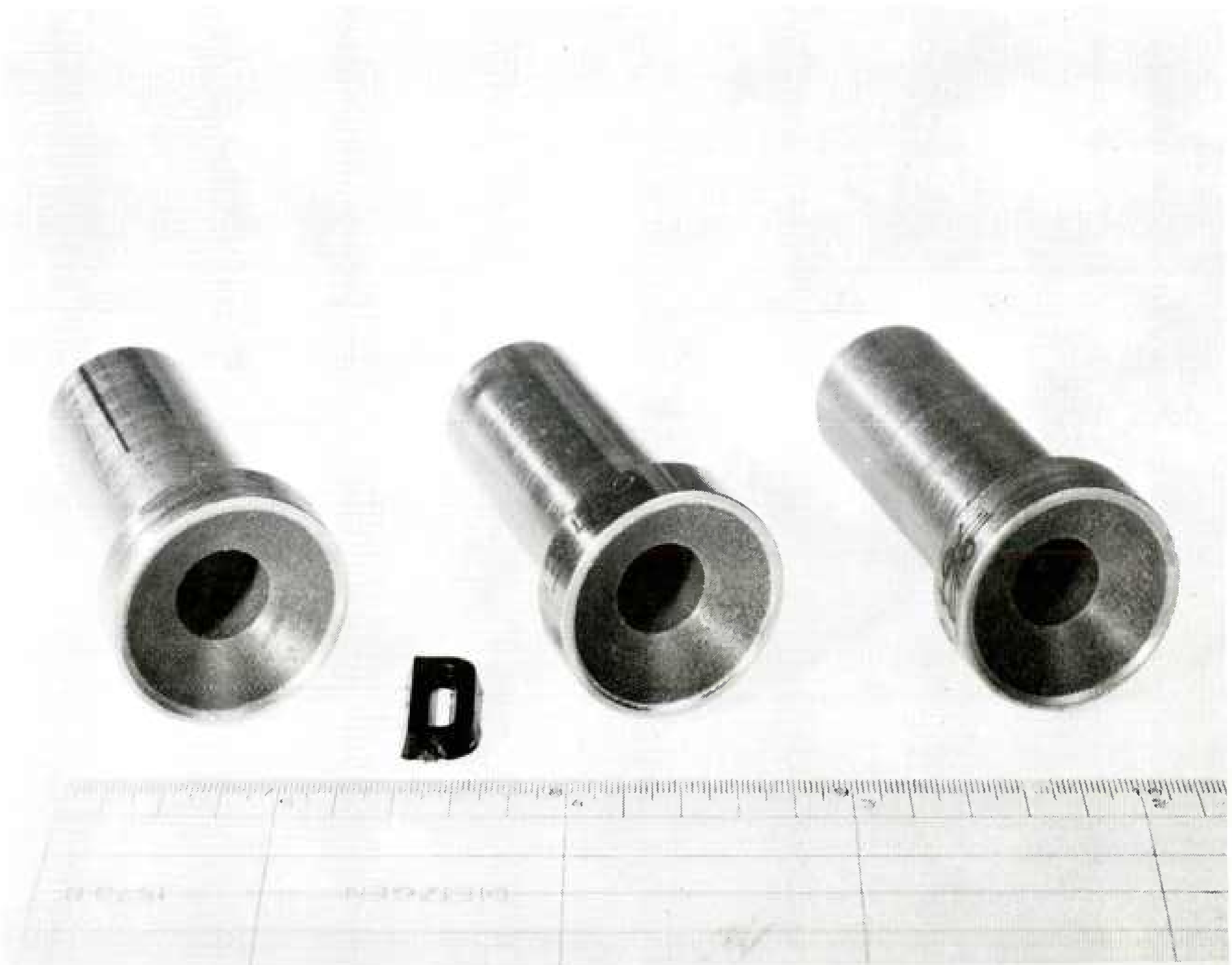

Figure 5. Delrin die agates ready for production use.

Figure 6. Graphite/Teflon/PPS die agates ready for production use.

Figure 7. Graphite/Teflon/nylon die agates ready for production use.

At the beginning of the evaluation, one cabinet of propellant from each die type was obtained, processed through the forced air dry, and sampled for closed bomb and complete physical measurement testing. The data obtained from these evaluations are presented in Table 4. Also presented in Table 4 for comparison are data of the propellant lot used as the ballistics standard, a similar recent production lot, and the applicable propellant specification limits. Additionally, normal green line processing data were accumulated periodically throughout the evaluation and are presented in Table 5.

Analysis of the relative quickness (RQ) data revealed no significant difference in mean RQ among the four types of die agates; however, the Teflon-coated steel agate showed the most uniformity and Delrin the least uniformity of the samples tested. Green propellant processing data, propellant strand, and green propellant granule physical measurements were normal throughout the performance evaluation. The propellant produced was within the current control limits and showed no significant differences between the die agate types.

During the evaluation period, samples of each agate type were selected on a routine basis and were submitted to Quality Control for standard physical and visual inspection. A summary of the agate ID dimensional data obtained throughout the evaluation, with appropriate statistical analyses, are presented in Tables 6 through 9 with results shown in Figure 8. Four dies from each group were measured (before and after three weeks of use) for agate approach angle, ID at the top of the agate approach surface, and the approximate radius of the agate approach. An image surface transfer using a molded facsimile blank was made to obtain these dimensions, and the data obtained are presented in Table 10. Following a review of these data, a decision was made not to obtain these data at the completion of the evaluation since the method of preparation of the facsimile blank and corresponding potential for variability in measurements did not warrant further consideration of this technique as a suitable tool for determining serviceability. Additionally, other data and visual observations were expected to more conclusively determine serviceability of the agates than the approach angle surface wear.

A preliminary review of data indicated that the selection of the agate type would be based on serviceability or capability of the part to withstand normal material handling processes without being damaged or destroyed. Green line process data and chemical/physical data of the propellant produced with the various agates indicated that the agate materials had little, if any, effect on either the propellant throughput or the quality of the finished product. For this reason, emphasis was given to the change in agate ID dimensions and visual appearance of the parts in determining wear characteristics and damages caused by the process. Therefore, a summary of observations by die agate type is presented in the following paragraphs.

TABLE 4A. M30 PROPELLANT PHYSICAL MEASUREMENTS IN METRIC UNITS

Die Type*	Die No.	Length Avg., mm	OD Avg., mm	Perf. Avg., mm	L/OD	OD/D	Web Average, mm		Web Diff., percent	Length Unif., σ	OD Unif., σ	Web Avg., mm	Relative Quickness, %		Relative Force, %	
							Inner	Outer					18°C	-40°C	18°C	-40°C
I	1-30	16.510	7.727	0.625	2.137	12.35	0.155	0.142	-9.32	0.89	1.36	0.148	93.88	90.80	99.74	98.54
II	101-130	16.383	7.805	0.602	2.099	12.95	0.151	0.151	0.31	1.07	1.14	0.151	94.95	90.13	100.31	98.26
III	201-230	16.586	7.790	0.620	2.129	12.59	0.149	0.151	1.41	1.36	1.33	0.150	95.55	90.73	99.97	97.95
IV	301-330	16.561	7.785	0.617	2.127	12.64	0.151	0.149	-0.93	0.97	1.06	0.150	94.43	90.83	99.95	98.30
Std Lot 68370		19.789	8.420	0.953	2.350	8.83	0.138	0.138		0.69	1.10	0.138	97.66	93.31	100.01	98.24
Spec. TDS 74251		--	--	--	2.10-2.50	5.0-15.0	--	--	15.0 max	6.25 max	3.125 max	--				
Last Production Lot 69703		16.264	7.724	0.607	2.11	12.72	0.147	0.149	2.0	0.90	1.37	0.148	96.40	92.14	99.94	98.31

* Die Type	Type Material
I	Teflon-Coated Steel
II	Delrin
III	Graphite, Teflon, PPS
IV	Graphite, Teflon, Nylon

TABLE 4B. M30 PROPELLANT PHYSICAL MEASUREMENTS IN CONVENTIONAL UNITS

Die Type*	Die No.	Length Avg., inch	OD Avg., inch	Perf. Avg., inch	L/OD, inch	OD/D, inch	Web Average, inch		Web Diff., percent	Length Unif., σ	OD Unif., σ	Web Avg., inch	Relative Quickness, %		Relative Force, %	
							Inner	Outer					+90°F	-40°F	+90°C	-40°F
I	1-30	0.650	0.3042	0.0246	2.137	12.35	0.0610	0.0556	-9.32	0.89	1.36	0.0583	93.88	90.80	99.74	98.54
II	101-130	0.645	0.3073	0.0237	2.099	12.95	0.0593	0.0595	0.31	1.07	1.14	0.0594	94.95	90.13	100.31	98.26
III	201-230	0.653	0.3067	0.0244	2.129	12.59	0.0585	0.0593	1.41	1.36	1.33	0.0589	95.55**	90.73	99.97	97.95
IV	301-330	0.652	0.3065	0.0243	2.127	12.64	0.0593	0.0587	-0.93	0.97	1.06	0.0590	94.43	90.83	99.95	98.30
Std Lot 68730		0.7791	0.3315	0.0375	2.35	8.8	0.0543	0.0545		0.69	1.10	0.0544	97.66	93.31	100.01	98.24
Spec. TDS 74251		--	--	--	2.10-2.50	5.0-15.0	--	--	15.0 max	6.25 max	3.125 max	--				
Last Production Lot 69708		0.6403	0.3041	0.0239	2.11	12.7	0.0578	0.0588	2.0	0.90	1.37	0.0583	96.40	92.14	99.94	98.31

* Die Type	Die Material
I	Teflon-Coated Steel
II	Delrin
III	Graphite, Teflon, PPS
IV	Graphite, Teflon, Nylon

**4 shots only, computer malfunctioned; propellant for resample not available

TABLE 5A. M30 PROPELLANT INSPECTION DATA IN METRIC UNITS

Inspection Date Shift	10/27/76 8-4-Z	11/2/76 4-12-Z	11/3/76 12-8-X	11/3/76 8-4-Y	11/9/76 4-12-Y	11/10/76 8-4-X	5/2/77 4-12-X
Teflon-Coated Steel Agates, Nos. 1-30							
Ave Length, mm	16.205	15.951	16.104	16.256	16.053	16.205	---
Ave OD, mm	8.738	8.661	8.738	8.712	8.687	8.534	8.738
Ave W_o, mm	1.397	1.524	1.397	1.448	1.422	1.499	1.524
Ave W_i, mm	1.621	1.626	1.626	1.575	1.626	1.473	1.626
Web Difference, %	14	6	17	8	12.5	2	6
Ave Perforation, mm	0.686	0.711	0.737	0.711	0.686	0.762	0.686
L/D	1.85	1.84	1.84	1.86	1.85	1.90	1.87
D/d	12.7	12.2	12.0	12.0	13.0	11.0	12.6
Ave Strand Wt, g	210.8	206.7	211.2	207.8	208.0	208.2	205.4
Propel. Qual. Score	147	---	112	132	170	154	144
Delrin Agates, Nos. 101-130							
Ave Length, mm	16.078	16.129	16.078	16.180	16.078	16.129	16.180
Ave OD, mm	8.763	8.661	8.585	8.712	8.687	8.611	8.661
Ave W_o, mm	1.549	1.473	1.473	1.473	1.524	1.473	1.473
Ave W_i, mm	1.524	1.600	1.524	1.626	1.524	1.549	1.473
Web Difference, %	2	8	3	10	0	5	0
Ave Perforation, mm	0.686	0.686	0.660	0.711	0.686	0.711	0.762
L/D	1.84	1.86	1.87	1.86	1.85	1.87	1.87
D/d	12.7	12.6	13.0	12.0	12.7	12.0	11.4
Ave Strand Wt, g	212.0	212.2	212.3	212.2	201.5	210.7	206.9
Propel. Qual. Score	165	---	113	130	196	137	148

TABLE 5A. (continued)

Inspection Date Shift	10/28/76 8-4-Z	11/2/76 4-12-Z	11/3/76 12-8-X	11/3/76 8-4-Y	11/9/76 4-12-Y	11/10/76 8-4-X	5/2/77 4-12-X
Graphite/Teflon/PPS Agates, Nos. 201-230							
Ave Length, mm	16.205	16.104	16.256	16.180	16.053	16.104	---
Ave OD, mm	8.738	8.661	8.738	8.712	8.738	8.611	8.712
Ave W_o, mm	1.397	1.524	1.422	1.473	1.499	1.524	1.524
Ave W_i, mm	1.626	1.575	1.575	1.524	1.524	1.575	1.524
Web Difference, %	14	3	10	3	2	3	0
Ave Perforation, mm	0.686	0.762	0.737	0.711	0.686	0.686	0.737
L/D	1.85	1.86	1.86	1.86	1.84	1.87	1.85
D/d	12.7	11.4	11.9	12.0	13.0	13.0	12.0
Ave Strand Wt, g	210.8	213.0	212.8	213.1	207.4	208.5	209.3
Propel. Qual. Score	159	---	158	103	100	119	168
Graphite/Teflon/Nylon Agates, Nos. 301-330							
Ave Length, mm	16.180	16.180	16.104	16.180	16.078	16.104	16.180
Ave OD, mm	8.763	8.585	8.712	8.712	8.661	8.585	8.636
Ave W_o, mm	1.524	1.448	1.524	1.524	1.473	1.372	1.524
Ave W_i, mm	1.575	1.524	1.600	1.524	1.549	1.626	1.524
Web Difference, %	3	5	5	0	5	17	0
Ave Perforation, mm	0.737	0.737	0.660	0.660	0.711	0.686	0.762
L/D	1.85	1.88	1.85	1.86	1.86	1.88	1.87
D/d	11.9	13.0	13.2	13.0	12.2	12.5	11.3
Ave Strand Wt, g	211.2	212.7	204.9	212.9	209.0	208.9	207.1
Propel. Qual. Score	170	---	174	137	174	155	120

TABLE 5B. M30 PROPELLANT INSPECTION DATA

Inspection Date Shift	10/27/76 8-4-Z	11/2/76 4-12-Z	11/3/76 12-8-X	11/3/76 8-4-Y	11/9/76 4-12-Y	11/10/76 8-4-X	5/2/77 4-12-X
Teflon-Coated Steel Agates, Nos. 1-30							
Ave Length, in	0.638	0.628	0.634	0.640	0.632	0.638	---
Ave OD, in	0.344	0.341	0.344	0.343	0.342	0.336	0.344
Ave W_o, in	0.055	0.060	0.055	0.057	0.056	0.059	0.060
Ave W_i, in	0.0638	0.064	0.064	0.062	0.064	0.058	0.064
Web Difference, %	14	6	17	8	12.5	2	6
Ave Perforation, in	0.027	0.028	0.029	0.028	0.027	0.030	0.027
L/D	1.85	1.84	1.84	1.86	1.85	1.90	1.87
D/d	12.7	12.2	12.0	12.0	13.0	11.0	12.6
Ave Strand Wt, g	210.8	206.7	211.2	207.8	208	208.2	205.4
Propel. Qual. Score	147	---	112	132	170	154	144
Delrin Agates, Nos. 101-130							
Ave Length, in	0.633	0.635	0.633	0.637	0.633	0.635	0.637
Ave OD, in	0.345	0.341	0.338	0.343	0.342	0.339	0.341
Ave W_o, in	0.061	0.058	0.058	0.058	0.060	0.058	0.058
Ave W_i, in	0.060	0.063	0.060	0.064	0.060	0.061	0.058
Web Difference, %	2	8	3	10	0	5	0
Ave Perforation, in	0.027	0.027	0.026	0.028	0.027	0.028	0.030
L/D	1.84	1.86	1.87	1.86	1.85	1.87	1.87
D/d	12.7	12.6	13.0	12.0	12.7	12.0	11.4
Ave Strand Wt, g	211.98	212.2	212.3	212.2	201.5	210.7	206.9
Propel. Qual. Score	165	---	113	130	196	137	148

TABLE 5B. (continued)

Inspection Date Shift	10/27/76 8-4-Z	11/2/76 4-12-Z	11/3/76 12-8-X	11/3/76 8-4-Y	11/9/76 4-12-Y	11/10/76 8-4-X	5/2/77 4-12-X
Graphite/Teflon/PPS Agates, Nos. 201-230							
Ave Length, in	0.638	0.634	0.640	0.637	0.632	0.634	---
Ave OD, in	0.344	0.341	0.344	0.343	0.344	0.339	0.343
Ave W_o, in	0.055	0.060	0.056	0.058	0.059	0.060	0.060
Ave W_i, in	0.064	0.062	0.062	0.060	0.060	0.062	0.060
Web Difference, %	14	3	10	3	2	3	0
Ave Perforation, in	0.027	0.030	0.029	0.028	0.027	0.027	0.029
L/D	1.85	1.86	1.86	1.86	1.84	1.87	1.85
D/d	12.7	11.4	11.9	12.0	13.0	13.0	12.0
Ave Strand Wt, g	210.8	212.98	212.78	213.1	207.4	208.5	209.3
Propel. Qual. Score	159	---	158	103	100	119	168
Graphite/Teflon/Nylon Agates, Nos. 301-330							
Ave Length, in	0.637	0.637	0.634	0.637	0.633	0.634	0.637
Ave OD, in	0.345	0.338	0.343	0.343	0.341	0.338	0.340
Ave W_o, in	0.060	0.057	0.060	0.060	0.058	0.054	0.060
Ave W_i, in	0.062	0.060	0.063	0.060	0.061	0.064	0.060
Web Difference, %	3	5	5	0	5	17	0
Ave Perforation, in	0.029	0.029	0.026	0.026	0.028	0.027	0.030
L/D	1.85	1.88	1.85	1.86	1.86	1.88	1.87
D/d	11.9	13.0	13.2	13.0	12.2	12.5	11.3
Ave Strand Wt, g	211.2	212.7	204.9	212.88	208.96	208.86	207.1
Propel. Qual. Score	170	---	174	137	174	155	120

TABLE 6A. WEAR MEASUREMENTS DATA FOR TEFLON-COATED DIES
(in metric units)

Sample No.	Agate Ser. No.	Agate, I.D., mm						
		Start	Week 1	Week 2	Week 3	Week 4	Week 5	Week 7
1	1	8.867	8.882	8.849	8.870	8.867	8.867	8.854
2	5	8.867	8.872	8.877	8.860	8.870	8.870	8.865
3	10	8.865	8.877	8.875	8.862	8.870	8.870	8.867
4	15	8.867	8.880	8.872	8.865	8.877	8.867	8.885
5	20	8.865	8.860	8.854	8.860	8.870	8.872	8.870
6	25	8.872	8.867	8.860	8.860	8.877	8.872	8.860
7	30	8.867	8.865	8.877	8.865	8.877	8.872	8.877
$\overline{X}$		8.86714	8.87197	8.86638	8.86282	8.87247	8.86993	8.86816
S		0.00254	0.00846	0.01171	0.00378	0.00450	0.00228	0.01036
R		0.00762	0.02286	0.02794	0.01016	0.01016	0.00508	0.03048

$\overline{\overline{X}}$ = 8.868410

$P_{\overline{X}}$ = 0.0033782

Sc = 0.0071882

$\overline{X}_H - \overline{X}_L$ = 0.009652

W = 0.014275

TABLE 6B. WEAR MEASUREMENTS DATA FOR TEFLON-COATED DIES

Sample No.	Agate Ser. No.	Agate, I.D., in Start	Week 1	Week 2	Week 3	Week 4	Week 5	Week 7
1	1	0.3491	0.3497	0.3484	0.3492	0.3491	0.3491	0.3486
2	5	0.3491	0.3493	0.3495	0.3488	0.3492	0.3492	0.3490
3	10	0.3490	0.3495	0.3494	0.3489	0.3492	0.3492	0.3491
4	15	0.3491	0.3496	0.3493	0.3490	0.3495	0.3491	0.3498
5	20	0.3490	0.3488	0.3486	0.3488	0.3492	0.3493	0.3492
6	25	0.3493	0.3491	0.3488	0.3488	0.3495	0.3493	0.3488
7	30	0.3491	0.3490	0.3495	0.3490	0.3495	0.3493	0.3495
$\overline{X}$		0.34910	0.34929	0.34907	0.34893	0.34931	0.34921	0.34914
S		0.000099	0.000333	0.000461	0.000149	0.000177	0.000089	0.000408
R		0.0003	0.0009	0.0011	0.0004	0.0004	0.0002	0.0012

$\overline{\overline{X}}$ = 0.349150

$P_{\overline{X}}$ = 0.0001330

Sc = 0.000283

$\overline{X}_H - \overline{X}_L$ = 0.00038

W = 0.000562

TABLE 7A. WEAR MEASUREMENT DATA FOR DELRIN DIES
(in metric units)

Sample No.	Agate Ser. No.	Agate, I.D., mm Start	Week 1	Week 2	Week 3	Week 4	Week 5	Week 7
1	101	8.870	8.839	8.819	8.832	8.834	8.816	8.804
2	105	8.870	8.860	8.827	8.814	8.809	8.791	8.804
3	110	8.867	8.839	8.819	8.809	8.809	8.799	8.821
4	115	8.870	8.854	8.827	8.839	8.832	8.799	8.801
5	120	8.865	8.842	8.827	8.834	8.821	8.804	8.799
6	125	8.865	8.842	8.824	8.824	8.814	8.801	---
7	130	8.867	8.834	8.814	8.834	8.819	8.801	8.788
$\overline{X}$		8.86739	8.84453	8.82218	8.82650	8.81964	8.80135	8.80288
S		0.002283	0.008966	0.005029	0.011455	0.010236	0.007671	0.010719
R		0.00508	0.00254	0.01270	0.00254	0.00254	0.00254	0.02286

$\overline{\overline{X}}$ = 8.826355

$P_{\overline{X}}$ = 0.023842

W = 0.017501

$X_H - X_L$ = 0.06604

A_e = 0.008636

TABLE 7B. WEAR MEASUREMENT DATA FOR DELRIN DIES

Sample No.	Agate Ser. No.	Agate, I.D., in						
		Start	Week 1	Week 2	Week 3	Week 4	Week 5	Week 7
1	101	0.3492	0.3480	0.3472	0.3477	0.3478	0.3471	0.3466
2	105	0.3492	0.3488	0.3475	0.3470	0.3468	0.3461	0.3466
3	110	0.3491	0.3480	0.3472	0.3468	0.3468	0.3464	0.3473
4	115	0.3492	0.3486	0.3475	0.3480	0.3477	0.3464	0.3465
5	120	0.3490	0.3481	0.3475	0.3478	0.3473	0.3466	0.3464
6	125	0.3490	0.3481	0.3474	0.3474	0.3470	0.3465	---
7	130	0.3491	0.3478	0.3470	0.3478	0.3472	0.3465	0.3460
$\overline{X}$		0.34911	0.34821	0.34733	0.34750	0.34723	0.34651	0.34657
S		0.0000899	0.000353	0.000198	0.000451	0.000403	0.000302	0.000422
R		0.0002	0.0010	0.0005	0.0010	0.0010	0.0010	0.0009

$\overline{\overline{X}} = 0.3474943$

$P_{\overline{X}} = 0.0009167$

$W = 0.000689$

$X_H - X_L = 0.0026$

$A_e = 0.000340$

TABLE 8A. WEAR MEASUREMENT DATA FOR GRAPHITE/TEFLON/PPS DIES
(in metric units)

Sample No.	Agate Ser. No.	Agate, I.D., mm Start	Week 1	Week 2	Week 3	Week 4	Week 5	Week 7
1	201	8.865	8.857	8.854	8.852	8.865	8.852	8.854
2	205	8.860	8.862	8.877	8.865	8.852	8.842	8.860
3	210	8.862	8.865	8.860	8.867	8.857	8.849	8.862
4	215	8.857	8.860	8.849	8.857	8.865	8.857	8.852
5	220	8.867	8.857	8.860	8.852	8.865	8.854	8.852
6	225	8.862	8.857	8.849	8.865	8.865	8.857	8.860
7	230	8.857	8.887	8.857	8.857	8.854	8.865	8.854
$\overline{X}$		8.86130	8.86384	8.85774	8.85927	8.86028	8.85368	8.85622
S		0.00378	0.01092	0.00991	0.00630	0.00561	0.00714	0.00406
R		0.00762	0.03048	0.03048	0.01524	0.01270	0.02286	0.01016

$\overline{\overline{X}} = 8.85891$

$S_{\overline{X}} = 0.003366$

$X_H - X_L = 0.01016$

$S_e = 0.008179$

$W = 0.016256$

TABLE 8B. WEAR MEASUREMENT DATA FOR GRAPHITE/TEFLON/PPS DIES

Sample No.	Agate Ser. No.	Agate, I.D., in						
		Start	Week 1	Week 2	Week 3	Week 4	Week 5	Week 7
1	201	0.3490	0.3487	0.3486	0.3485	0.3490	0.3485	0.3486
2	205	0.3488	0.3489	0.3495	0.3490	0.3485	0.3481	0.3488
3	210	0.3489	0.3490	0.3488	0.3491	0.3487	0.3484	0.3489
4	215	0.3487	0.3488	0.3483	0.3487	0.3490	0.3487	0.3485
5	220	0.3491	0.3487	0.3488	0.3485	0.3490	0.3486	0.3485
6	225	0.3489	0.3487	0.3484	0.3490	0.3490	0.3487	0.3488
7	230	0.3487	0.3499	0.3487	0.3487	0.3486	0.3490	0.3486
$\overline{X}$		0.34887	0.34897	0.34873	0.34879	0.34883	0.34857	0.34867
S		0.000149	0.000430	0.000390	0.000248	0.000221	0.000281	0.000160
R		0.0003	0.0012	0.0012	0.0006	0.0005	0.0009	0.0004

$\overline{\overline{X}}$ = 0.348776

$S_{\overline{X}}$ = 0.0001325

$X_H - X_L$ = 0.0004

S_e = 0.000322

W = 0.000640

TABLE 9A. WEAR MEASUREMENT DATA FOR GRAPHITE/TEFLON/NYLON DIES (in metric units)

Sample No.	Agate Ser. No.	Agate, I.D., mm Start	Week 1	Week 2	Week 3	Week 4	Week 5
1	301	8.860	8.867	8.867	8.839	8.842	8.832
2	305	8.862	8.865	8.852	8.842	8.832	8.824
3	310	8.857	8.862	8.852	8.839	8.854	8.837
4	315	8.857	8.865	8.852	8.839	8.842	8.811
5	320	8.860	8.849	8.865	8.865	8.847	8.839
6	325	8.857	8.865	8.849	8.872	8.870	8.849
7	330	8.860	8.857	8.847	8.839	8.829	8.816
$\overline{X}$		8.85876	8.86130	8.85469	8.84784	8.84504	8.82980
S		0.01920	0.00617	0.00782	0.01420	0.01389	0.01341
R		0.00051	0.01778	0.00203	0.03302	0.04064	0.03810

$\overline{\overline{X}} = 8.84956$

$S_{\overline{X}} = 0.0115113$

$S_e = 0.0106172$

$W = 0.022515$

$X_H - X_L = 0.031496$

TABLE 9B. WEAR MEASUREMENT DATA FOR GRAPHITE/TEFLON/NYLON DIES

Sample No.	Agate Ser. No.	Agate, I.D., in					
		Start	Week 1	Week 2	Week 3	Week 4	Week 5
1	301	0.3488	0.3491	0.3491	0.3480	0.3481	0.3477
2	305	0.3489	0.3490	0.3485	0.3481	0.3477	0.3474
3	310	0.3487	0.3489	0.3485	0.3480	0.3486	0.3479
4	315	0.3487	0.3490	0.3485	0.3480	0.3481	0.3469
5	320	0.3488	0.3484	0.3490	0.3490	0.3483	0.3480
6	325	0.3487	0.3490	0.3484	0.3493	0.3492	0.3484
7	330	0.3488	0.3487	0.3483	0.3480	0.3476	0.3471
$\overline{X}$		0.34877	0.34887	0.34861	0.34834	0.34823	0.34763
S		0.0000756	0.000243	0.000308	0.000559	0.000547	0.000528
R		0.00002	0.0007	0.00008	0.0013	0.0016	0.0015

$\overline{\overline{X}} = 0.348408$

$S_{\overline{\overline{X}}} = 0.0004532$

$S_e = 0.000418$

$W = 0.0008864$

$X_H - X_L = 0.00124$

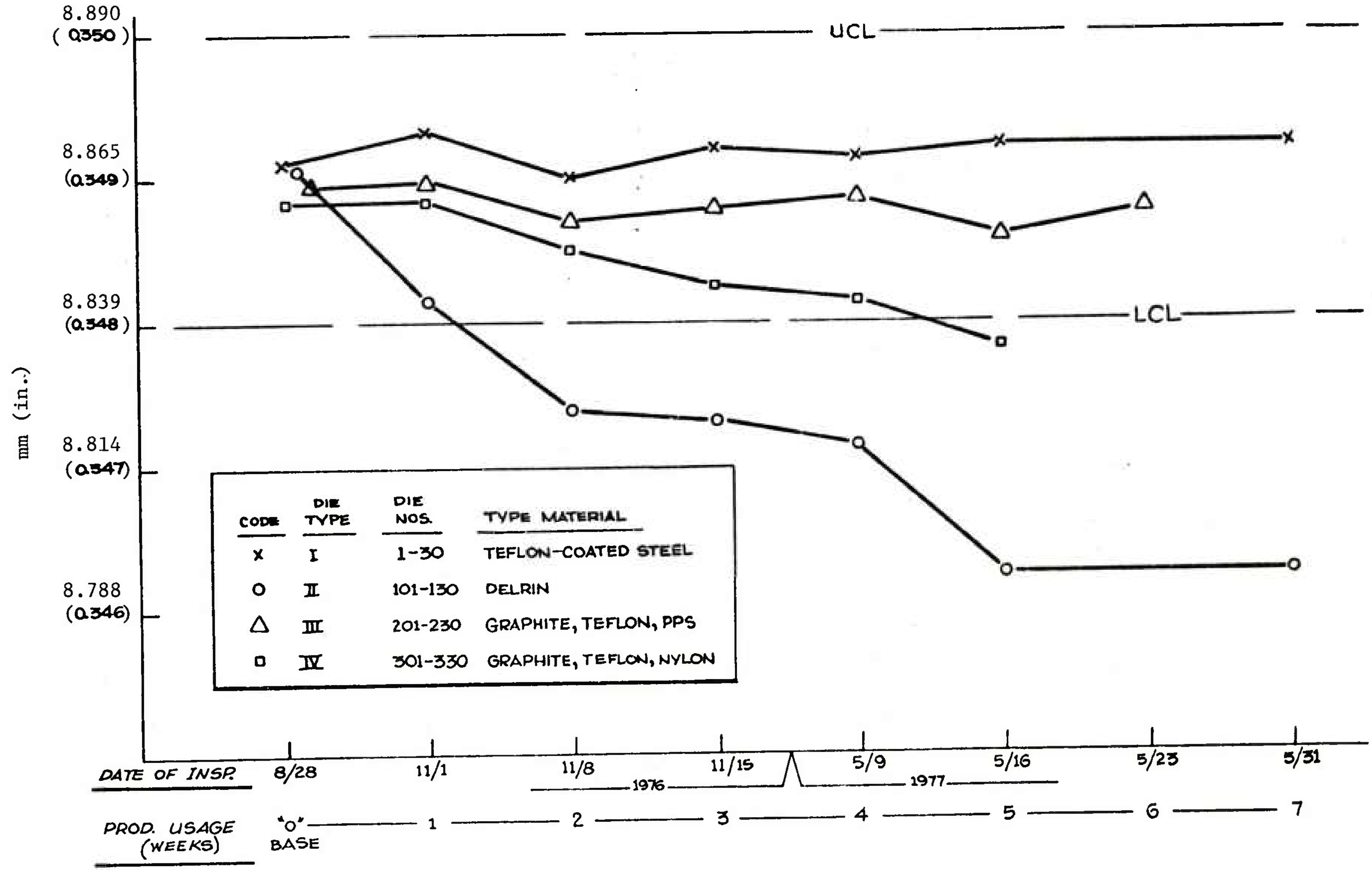

Figure 8. Comparative plot of die agate ID measurements versus time.

TABLE 10. DIE APPROACH WEAR MEASUREMENTS

Type Die*	Ave ID Top of Agate				Ave Agate Approach Angle				Radius of Agate Approach			
	Start		3d Week		Start		3d Week		Start		3d Week	
	in	mm	in	mm	Deg	Rad	Deg	Rad	Deg	Rad	Deg	Rad
I	0.715	18.161	0.681	17.297	120°30'	2.103	120°18'	2.100	0	0	0	0
II	0.825	20.955	0.815	20.701	119°32'	2.086	119°34'	2.087	0	0	0	0
III	0.805	20.447	0.800	20.320	121°39'	2.123	122° 9'	2.132	0	0	0	0
IV	0.804	20.422	0.803	20.396	120° 0'	2.094	120°29'	2.103	0	0	0	0

*I - Teflon-coated steel

II - Delrin

III - Graphite/Teflon/PPS

IV - Graphite/Teflon/nylon

1. Teflon-Coated Steel Agates

Table 6 presents a summary of the agate ID physical measurement data obtained for the Teflon-coated steel agates and compares the original (before production) dimensional data to that obtained throughout the evaluation. Statistical analysis of these data show that the ID dimensions of the agates did not change significantly.

A review of the data in Table 6 (plotted on Figure 8) shows that the Teflon-coated steel die agates underwent the least change of any of the die agate types evaluated and, in fact, did provide a significant degree of dimensional stability. Thus, Teflon-coated steel is an excellent candidate for a standard die agate.

A careful inspection of representative samples of agates after one week of use showed some irregularity in the continuity of the coated surface near the center area of the agate ID. This was observed as a result of the measurement technique in which a dial indicator gage was moved up and down the inside of the barrel ID, and an irregular surface was indicated. This discontinuity was thought to be caused either by a slight breakdown of the Teflon coating or by wear. The original inspection prior to use did not indicate this condition. It was concluded that a slight breakdown of the Teflon coating in the center of the agate barrel ID allowed the Teflon to flow down the barrel to the exit surface. This condition was further substantiated by an inspection after three weeks of use. At that time, a slight buildup of material [approximately 0.025 mm (0.001 in)] was observed on the extreme outer edge of the agate exit ID. The center area of the agate ID surface was also observed to be rough when compared to the rest of the barrel ID.

Although physical measurements of the agate ID exit area at the end of the evaluation failed to show any significant buildup or change, visual inspection of the center of the agates still indicated various conditions of coating discontinuity when viewed from either end. It was not possible during this study to accurately determine whether the coating was breaking down and flowing, but the change in coating appearance was an indication of coating change during usage. This condition needs further substantiation. Thus, if this type of material is used for die agates, a more extensive evaluation should be attempted. The inspection results of the Teflon-coated agates obtained after seven weeks of usage are presented in Table 11 with typical photographic examples (Figure 9). Figure 10 is an enlarged view of the agate inside surface at the exit end; it shows that irregular coating scratches were observed in practically all of the agates. A microscopic examination led to the conclusion that these scratches were not caused by the normal breakdown of the coating due to usage but were caused by some type of mechanical action involved with propellant manufacturing or the agate cleaning process.

TABLE 11. SUMMARY OF FINAL INSPECTION DATA FOR TEFLON-COATED STEEL DIE AGATES (End of Week 7)

Die No.	Agate Diameter						Remarks
	Approach		Middle		Exit		
	mm	in.	mm	in.	mm	in.	
1	8.865	0.3490	8.854	0.3486	8.860	0.3488	Worn place in ID - approx 1/2 length of die
2	8.870	0.3492	8.882	0.3497	8.870	0.3492	Worn place in ID - full length
3	8.870	0.3492	8.860	0.3488	8.865	0.3490	Worn place in ctr of ID - approx 3/4 of circum
4	8.877	0.3495	8.865	0.3490	8.877	0.3495	Worn place in ctr of ID - approx 3/4 in. long Tool scars 1/4 in. up ID from aft end
5	8.870	0.3492	8.865	0.3490	8.870	0.3492	Worn place in ctr of ID - approx 1/2 of circum
6	8.870	0.3492	8.870	0.3492	8.867	0.3491	Worn place in ctr of ID - approx one in. long and 3/4 of circum in ctr
7	8.880	0.3496	8.877	0.3495	8.875	0.3494	Worn place in ctr of ID - approx 1/2 of circum Small scar in ID near exit area
8	8.870	0.3492	8.875	0.3494	8.877	0.3495	
9	8.870	0.3492	8.862	0.3489	8.865	0.3490	
10	8.877	0.3495	8.867	0.3491	8.865	0.3490	Thin mark in ctr of ID approx 3/4 in. long Fine scratches in ID at top and bottom for 1/4 in.
11	8.865	0.3490	8.862	0.3489	8.865	0.3490	Worn place in ctr of ID approx one in. long and at ctr approx 3/4 of circum
12	8.880	0.3496	8.867	0.3491	8.867	0.3491	Slight wave in ctr of ID - approx 1/2 circum
13	8.877	0.3495	8.877	0.3495	8.877	0.3495	Worn place in ctr of ID approx one in. and at ctr approx 3/4 of circum
14	8.872	0.3493	8.872	0.3493	8.870	0.3492	Spiral worn place in ID approx 3/16 in. wide by 3/4 in. long
15	8.870	0.3492	8.885	0.3498	8.872	0.3493	Worn place in ID. Three spiral places 3/4 of the length and 3/4 of circum
16	8.867	0.3491	8.867	0.3491	8.870	0.3492	Worn place in ctr of ID approx one in. long and at ctr 1/2 of circum
17	8.872	0.3493	8.870	0.3492	8.875	0.3494	Worn place in ID 1/4 in. from approach, 3/4 of circum
18	8.875	0.3494	8.880	0.3496	8.867	0.3491	Worn place in ID approx 1/2 in. from approach, approx 3/4 of circum. Slight circular corrugations
19	8.870	0.3492	8.875	0.3494	8.870	0.3492	Two worn places in ID (spiral) approx 1 1/2 in. long and straight place 3/4 in. long

TABLE 11. (Continued)

Die No.	Agate Diameter: Approach mm	Approach in.	Middle mm	Middle in.	Exit mm	Exit in.	Remarks
20	8.875	0.3494	8.870	0.3492	8.867	0.3491	Spiral worn place in ID near approach full circum approx one in. down
21	8.867	0.3491	8.867	0.3491	8.867	0.3491	
22	8.872	0.3493	8.875	0.3494	8.877	0.3495	Worn place in ID spiral approx. 1/3 circum
23	8.872	0.3493	8.867	0.3491	8.867	0.3491	
24	8.867	0.3491	8.867	0.3491	8.867	0.3491	Worn place in ID at ctr 1/2 circum and one straight place approx one in. long
25	8.867	0.3491	8.860	0.3488	8.865	0.3490	Worn place in ID running full length approx 3/16 in. wide
26	8.877	0.3495	8.875	0.3494	8.870	0.3492	Spiral worn place in ID approx 1/4 in. from approach and 3/4 of circum
27	8.870	0.3492	8.867	0.3491	8.870	0.3492	Worn place in ID approx 1/2 circum
28	8.867	0.3491	8.867	0.3491	8.870	0.3492	Worn place in ID 1/4 in. wide full length and 3/4 of circum at ctr
29	8.870	0.3492	8.870	0.3492	8.865	0.3490	Worn places in ctr of ID to exit end approx 50% of area
30	8.870	0.3492	8.877	0.3495	8.872	0.3493	Worn place in ID approx one in. and 1/3 of circum at ctr. Spiral 1/2 in. from exit
$\overline{X}_{30}$	8.872	0.3493	8.870	0.3492	8.870	0.3492	
R	0.01524	0.0006	0.03048	0.0012	0.01778	0.0007	

NOTE: It was found that the majority of agates in ID show fine lines like brush marks or tool marks partially in exit end and generally up into the agate barrel 1/4 to 1/2 inch from exit.

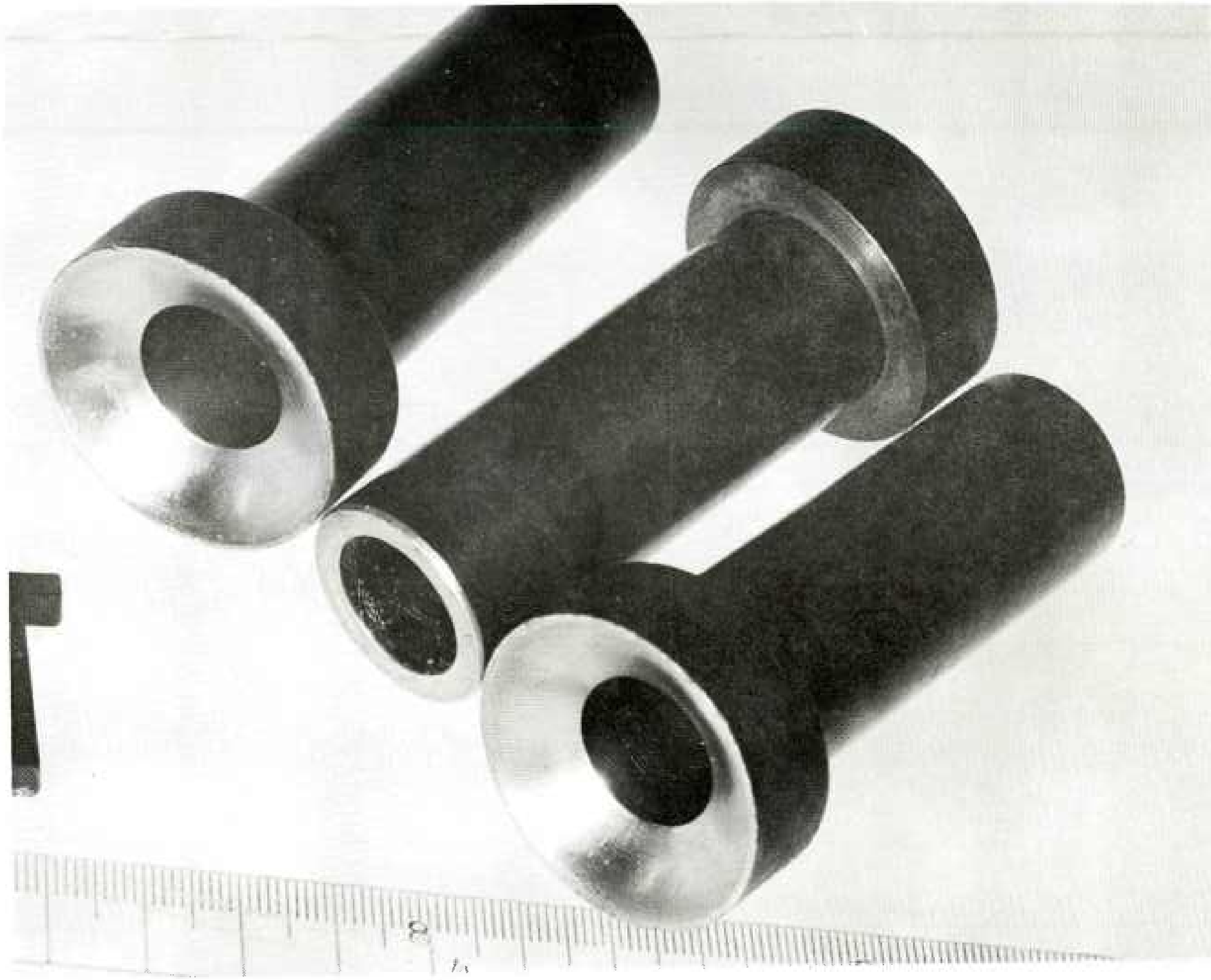

Figure 9. Typical Teflon-coated steel die agates following seven weeks of production use.

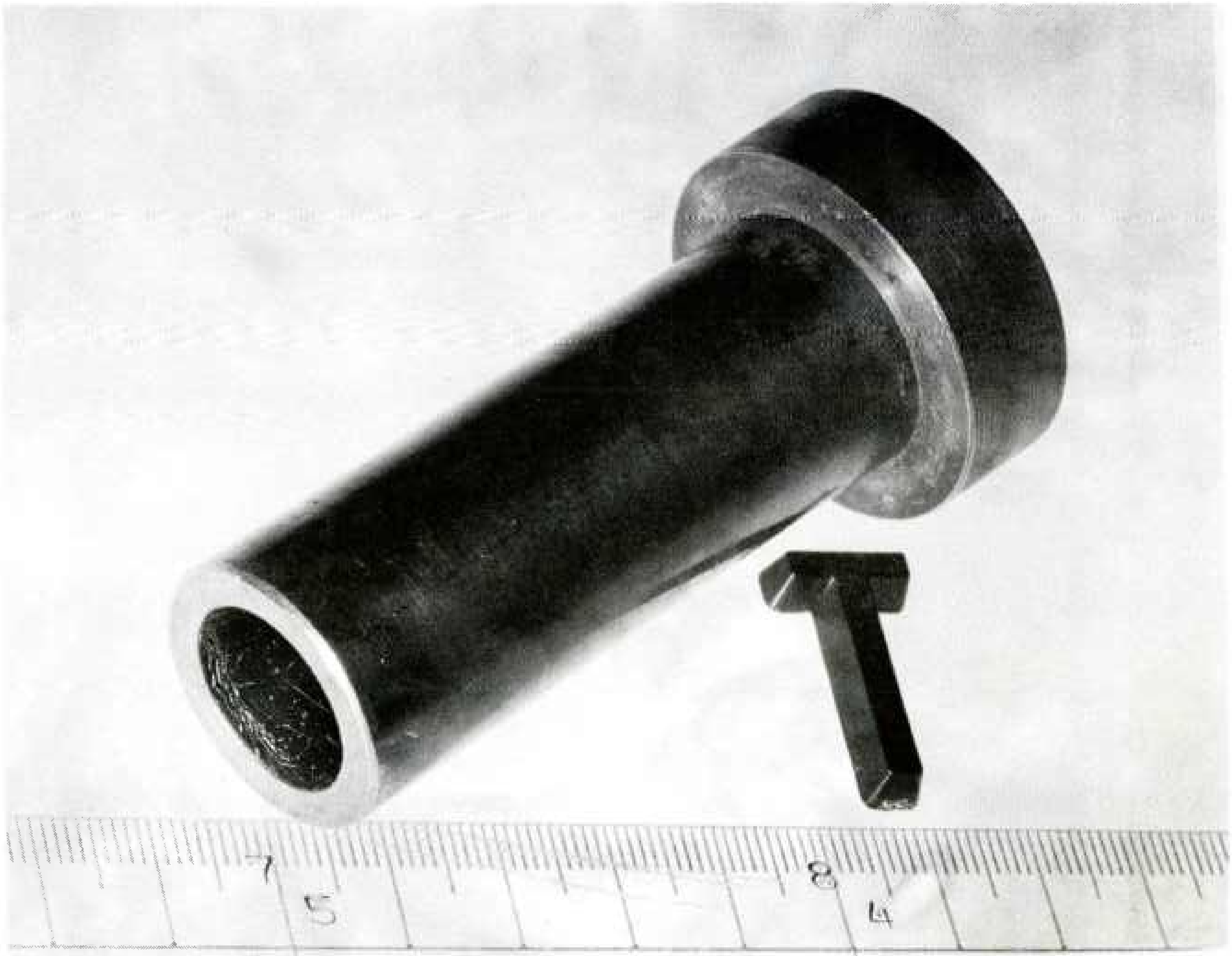

Figure 10. Typical example of damaged Teflon coating in agate exit ID surface.

2. Delrin Die Agates

Figure 8 contains a plot of the die agate ID measurements of representative Delrin die agates. It shows that the die agate ID measurements approached the established quality control lower limits of 8.839 mm (0.348 in) after the first week of use and were beyond the lower limit on each subsequent inspection throughout the evaluation.

A decision was made to leave these dies in production even though the ID measurements were beyond the current process control limits since: (a) the green propellant produced with them met all of the existing process control limits; (b) originally they were intended as the true comparison dies because they were identical to those used in regular production and should undergo the same amount of production usage and operating conditions as the graphite composition dies; and (c) to rework (ream) them after only one week would likely negate their effectiveness as true standard dies even though in regular production usage, this might have been done.

It was also known, initially, that because of a change in production requirements, this propellant item (M30) was planned to be on the production schedule for only a two to three week period. Thus, any die downtime was critical in obtaining comparable wear and service data (useful life) on each die configuration.

Table 7 presents a summary of the agate ID data obtained for the selected samples of Delrin-type agates and compares the original agate ID measurements for the middle of the agate barrel to that obtained throughout the evaluation period. These data show a gradual reduction in the agate ID over the entire period of evaluation with averaged measurements changing from an original agate ID measurement of 8.867 mm (0.3491 in) to a final ID measurement of 8.793 mm (0.3462 in). A statistical analysis performed on these data showed the change in ID to be highly significant. A review of the data in Table 7 (plotted in Figure 8) also shows that the Delrin agates changed in more ID dimensions than any of the four agate types used in this evaluation.

Die agate No. 123 was removed from production during the fourth week and agate No. 102 was removed during the fifth week because of broken pins.

Agate No. 125 was removed from production during the fourth week of use because it was producing a propellant strand with an irregular, raised surface. An examination of this agate following disassembly of the die holder immediately upon removal from the press showed that the exit ID surface of the Delrin agate material had been sliced as though it had been cut with a knife (Figure 11). Concurrently, the Propellant Department's die cleaning foreman reported several Delrin agates from other presses that

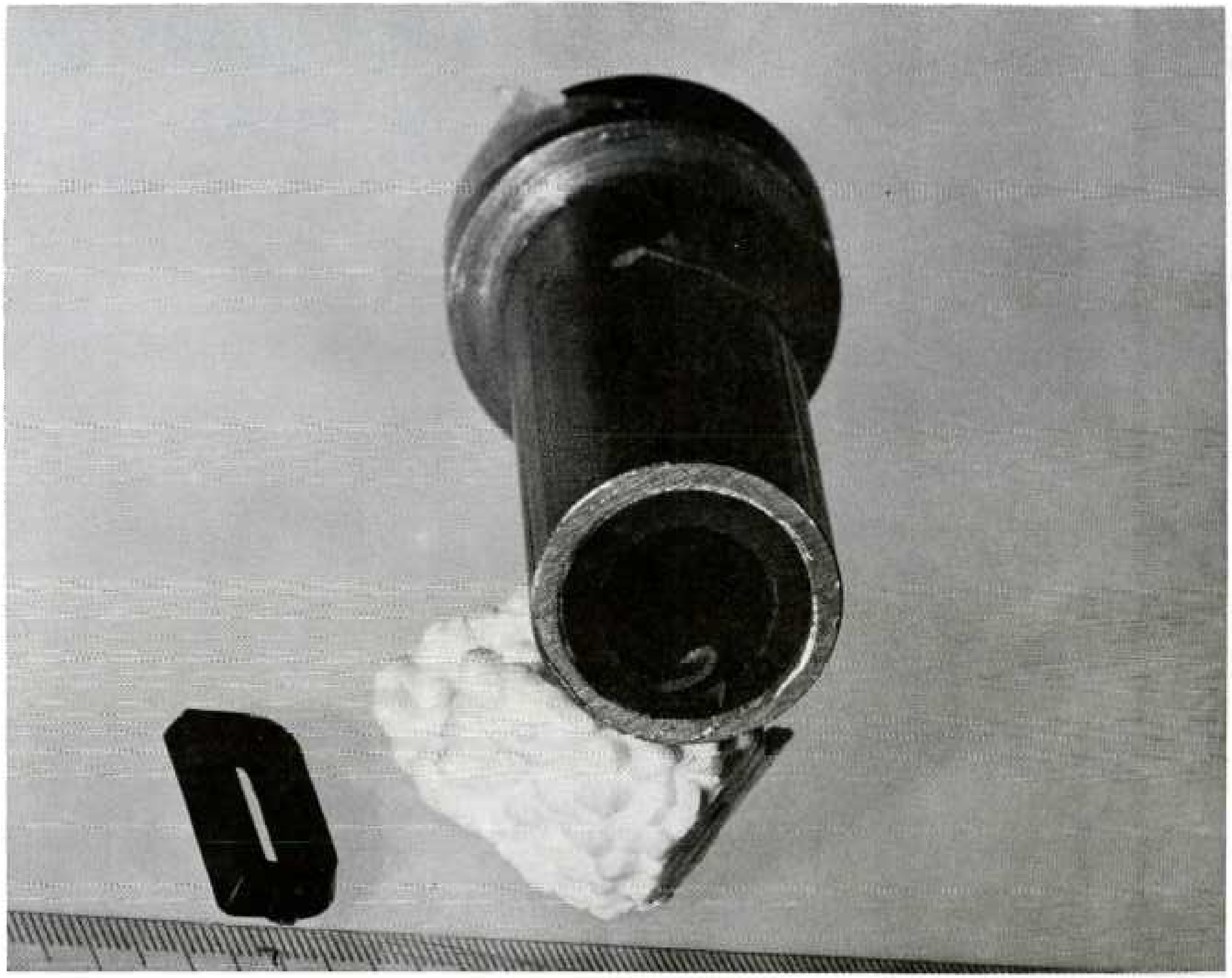

Figure 11. Delrin agate showing damage after four weeks use.

had been cut or damaged in the same manner. It was theorized by the Propellant Department's supervisory personnel that the cuts may have been caused by a brass corkscrew or a knife used by production operators attempting to remove propellant from plugged die agates. Agates Nos. 110, 128, and 129 were observed during inspection at the completion of five weeks evaluation to contain bad chips or cuts on the agate exit ID surface likely caused in the same way as agate No. 125. Agate No. 128 was also visibly out of round at the exit end. Of these agates, Nos. 128 and 129 were considered to be damaged sufficiently to cause them to be removed drom production. Figure 12 is a photograph of Delrin agate No. 129 and is representative of the agates showing damage to the exit web surface due to some type of tool damage. Note the evidence of the faint circular cut ring in the Delrin web surface which is presumed to be caused by the die removal tool. This appears to be the same cut rings that have caused significant damage to the graphite agates which will be discussed later.

A summary of the significant visual defects observed at the completion of the seven-week evaluation follows:

a.	Damage to approach angle surface of agate	5
b.	Chipped or cut agate web surface at exit ID	3
c.	Broken pins	2
d.	Eroded spots in the center of the inside diameter surface of the agate barrel	2

The actual inspection results following the seven weeks of usage are presented in Table 12.

It was obvious after reviewing the accumulated data that the dimensional instability of the Delrin agate was not due to fatigue or wear but rather to some action affecting the Delrin material itself, either during contact with propellant ingredients or during the agate cleaning operation which caused it to swell. Information from experienced supervisory personnel in the Propellant Department indicated that this was the normal occurrence.

Since the dies were to be taken out of production after only three weeks of use due to a change in the overall production schedule, a decision was made to store all dies under ambient conditions for at least one week and then to remeasure them to see what effect, if any, this delay time had on die agate dimensions.

A later change in the production schedule caused the propellant item which utilized these agates to be removed from the immediate manufacturing schedule. Thus, the dies were stored under ambient conditions for over five months.

Figure 12. Delrin agate which has a damaged exit web and shows evidence of damage caused by the die agate removal tool.

TABLE 12. SUMMARY OF FINAL INSPECTION DATA FOR DELRIN DIE AGATES (End of Week 7)

Die	Agate Diameter						
	Approach		Middle		Exit		
No.	mm	in.	mm	in.	mm	in.	Remarks
101	8.814	0.3470	8.804	0.3466	8.809	0.3468	
102	--	--	--	--	--	--	Broken. Pin removed at week 5
103	8.781	0.3457	8.801	0.3465	8.806	0.3467	
104	8.796	0.3463	8.809	0.3468	8.806	0.3467	
105	8.801	0.3465	8.804	0.3466	8.799	0.3464	Damage to top of approach angle
106	8.788	0.3460	8.796	0.3463	8.811	0.3469	
107	8.799	0.3464	8.781	0.3457	8.809	0.3468	
108	8.778	0.3456	8.806	0.3467	8.811	0.3469	
109	8.793	0.3462	8.793	0.3462	8.814	0.3470	Small worn spot in ctr of ID
110	8.819	0.3472	8.821	0.3473	8.821	0.3473	Three damaged spots in approach angle. Two scars in ctr of ID approx 0.010 x 1/2 in. Damaged web at exit end
111	8.806	0.3467	8.778	0.3456	8.804	0.3466	
112	8.788	0.3460	8.786	0.3459	0.796	0.3463	Small damage (rings) in approach angle rear ID. Ring in web at exit end, done by disassembly
					8.866	0.3467	
113	8.793	0.3462	8.778	0.3456	8.788	0.3460	
					8.804	0.3466	
114	8.778	0.3456	8.796	0.3463	8.804	0.3466	
115	8.776	0.3455	8.801	0.3465	8.809	0.3468	
116	8.776	0.3455	8.799	0.3464	8.796	0.3463	Small eroded place 1/4 in. from approach in ID
117	8.766	0.3451	8.788	0.3460	8.796	0.3463	
118	8.776	0.3455	8.793	0.3462	8.809	0.3468	
119	8.778	0.3456	8.783	0.3458	8.806	0.3467	

TABLE 12. (Continued)

Die No.	Agate Diameter: Approach mm	Approach in.	Middle mm	Middle in.	Exit mm	Exit in.	Remarks
					8.806	0.3467	
120	8.788	0.3460	8.799	0.3464	8.824	0.3474	
121	8.788	0.3460	8.793	0.3462	8.796	0.3463	
					8.799	0.3464	
122	8.768	0.3452	8.786	0.3459	8.809	0.3468	
123	--	--	--	--	--	--	Broken pin; removed at week 4
124	--	--	--	--	--	--	Missing
125	--	--	--	--	--	--	Cut in exit ID; removed at week 4
126	8.809	0.3468	8.788	0.3460	8.811	0.3469	Small cut in approach angle next to ID
127	8.793	0.3462	8.788	0.3460	8.804	0.3466	
128	--	--	--	--	--	--	Chip or cut web in exit area. Visibly out of round; removed at week 5
129	--	--	--	--	--	--	Chip or cut web in exit area. Production damage; removed at week 5
130	8.788	0.3460	8.788	0.3460	8.814	0.3470	
$\overline{X}_{30}$	8.788	0.3460	8.793	0.3462	8.806	0.3467	
R	0.0535	0.0021	0.0432	0.0017	0.0254	0.0010	

All four die types were then inspected. A summary of the data by die agate type and lapsed time since last used in production are given as follows:

	Barrel ID Before Introduction to Propellant		Barrel ID after 3 Weeks in Production		ID After 1 Week Ambient Storage		ID After 5 Months Ambient Storage	
	inch	mm	inch	mm	inch	mm	inch	mm
Teflon/Steel	0.3491	8.867	0.3492	8.870	0.3491	8.867	0.3492	8.870
Delrin	0.3491	8.867	0.3473	8.821	0.3484	8.849	0.3483	8.847
Graphite/Teflon/PPS	0.3490	8.865	0.3488	8.860	0.3490	8.865	0.3492	8.870
Graphite/Teflon/Nylon	0.3489	8.862	0.3482	8.844	0.3488	8.860	0.3489	8.862

The above data were not used in a statistical analysis; however, it can be readily seen that the Delrin agates reacted more significantly to exposure to propellant and/or die cleaning solvents and showed the greatest degree of change due to ambient storage. There does not appear, from these data, to be any basis for holding Delrin agates more than one week for shrinking to production limits as is now the production practice. Accordingly, it was noted that the graphite/Teflon/nylon composition die agates behaved very similarly to the Delrin agates but to a lesser degree.

As an addition to the scope of the project, a study was proposed (to be conducted under controlled laboratory conditions) to isolate the cause of this apparent dimensional instability. Prior to conducting this study, however, it was decided to perform a quick laboratory test of die material from the die shop borings to try to ascertain whether the agate dimensional instability was caused by the acetone cleaning solvent or by propellant constituents.

Samples of Delrin shavings were obtained from the die agate boring drill from approximately 35 to 40 regular production dies and analyzed by infrared spectrophotometry which showed 1.9 percent nitroglycerin (NG) and no acetone. A second sample was obtained by boring about half the wall thickness of the Delrin material out of one regular production die agate that was selected at random. The data reported by the laboratory for this sample was 2.4 percent NG and no acetone. It was concluded that the NG in the propellant was being absorbed by Delrin, causing it to swell. No further attempt was made to determine the effects of other propellant ingredients or cleaning solvents on Delrin.

3. Graphite Composition Die Agates

Both the graphite/Teflon/PPS and the graphite/Teflon/nylon agates are discussed below with similar performance characteristics and/or differences highlighted because of overall similarities of the agates and evaluation methods used for comparison.

A review of the physical measurement data presented in Tables 8 and 9 and highlighted in Figure 8 shows that over the period of this evaluation the graphite/Teflon/PPS agates did not undergo dimensional changes. The graphite/Teflon/nylon agates did change and behaved in a similar manner but to a lesser extent that the Delrin agates previously discussed. Therefore, from a dimensional standpoint, only the graphite/Teflon/PPS agate is deemed to be satisfactory. The graphite/Teflon/PPS agates were found to have dimensional stability similar to the Teflon-coated steel.

Results of inspection after the second week of usage showed visual wear or ovality occurring at the top [0.635 mm (0.025 in)] of the agate barrel ID surface of the graphite/Teflon/nylon agates. This was confirmed by measurements, as shown in the following examples:

	Before		After	
	mm	inch	mm	inch
Agate No. 302	8.900	0.3504	8.832	0.3477
Agate No. 307	8.903	0.3505	8.847	0.3483

After the third week of production use, all of the graphite/Teflon/nylon type agates were found to exhibit the same wear (ovality) characteristics as were found in the second week with a range of dimensions of 0.102 mm (0.004 in) [8.928 mm to 8.824 mm (0.3515 in to 0.3474 in)]. None of the other types of die agates displayed any significant wear or ovality as was experienced by the graphite/Teflon/nylon agates.

After the fourth week of usage, the graphite/Teflon/nylon agates began to show rather significant wear and/or defects, although the defects generally were not considered to be sufficiently severe to warrant removal of the entire group from the evaluation. The more significant deviations are noted below:

a. No. 301 - The top 12.7 mm (0.5 in) of the barrel ID was visibly oval with an ovality dimension of 0.0737 mm (0.0029 in) recorded.

b. No. 308 - The agate approach angle surface was observed to have six oval, "shiny" spots resembling "cloverleaves" which tended to

match the size and location of the perforations in the die pin plate. The "shiny" spots were assumed to be erosion marks (Figure 13) on the agate surface, caused by propellant flow following the fifth week of use.

c. No. 309 - Two small erosion scars or hair-line cracks were observed in the center area of the agate barrel ID.

d. No. 310 - Five deep gouge marks were observed in the agate barrel ID. Several of these marks resembled open-edged frayed fissure lines or voids (Figure 14). This agate was removed from the evaluation at this point.

e. No. 312 - This agate contained a chip in the outer edge of the approach angle surface. It also contained a small raised surface in the ID surface near the exit.

f. No. 317 - This agate contained numerous pits (i.e., voids the approximate size of a pin point) in the agate approach angle surface. There was also a small chip in the outer edge of the approach angle surface.

g. No. 325 - This agate contained small pits in the approach angle surface similar to No. 317. It also displayed ovality of 0.051 to 0.076 mm (0.002 to 0.003 in) for the upper two-thirds length of the ID surfaces, indicating a continuing erosion of material during usage.

h. No. 326 - The agate contained several small chips in the outer approach angle surface.

i. No. 328 - This agate contained chips in the agate exit web surface and in the ID exit corner of the web surface.

j. No. 330 - This agate contained chips in the agate exit surface.

A review of the inspection data obtained for the graphite/Teflon/nylon agates after five weeks of usage showed such a variety of physical and visual defects and excessive agate ID dimensional wear and ovality that a decision was made to discontinue the evaluation of this material. Many of the defects (Figure 15) were apparently caused by tools and apparently occurred as a result of the die agate removal from the die holder and resulting cleaning activities (some of which are similar to those observed for the graphite/Teflon/PPS die agates). They were not judged to be damaged enough to warrant their removal for this type of defect. However, the one area causing the greatest concern was the presence of pinholes, voids, and fissures, some minute and some quite large, which existed in varying degrees in approximately 50 percent of the agates. Figure 14 shows typical pinholes and fissures in the agate ID surfaces; Figure 16 is an enlargement of an area showing the voids in agate No. 325

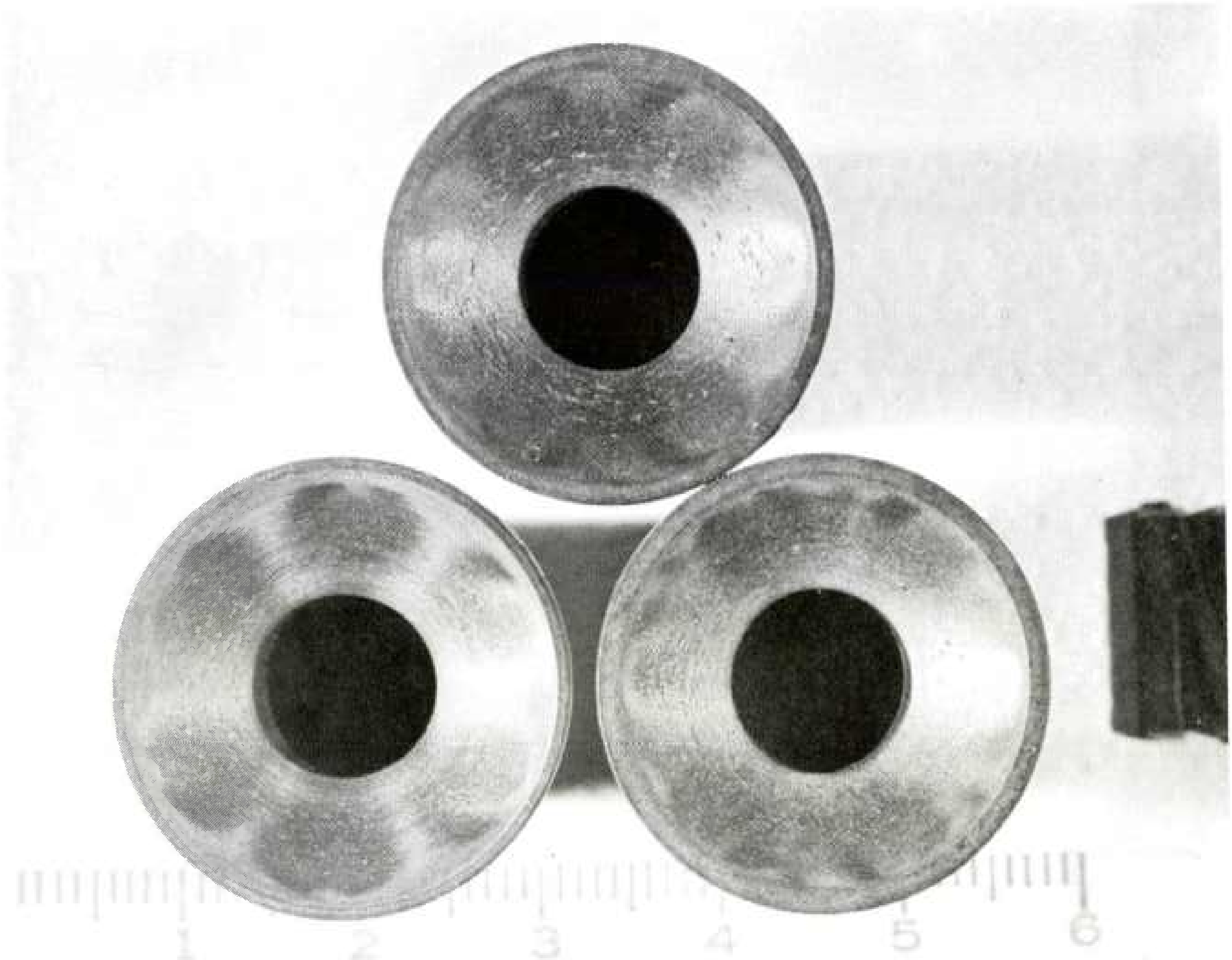

Figure 13. Graphite/Teflon/nylon agates (bottom) showing irregular wear on the agate approach angle surface. Top single agate shows pits and porosity in the approach angle surface.

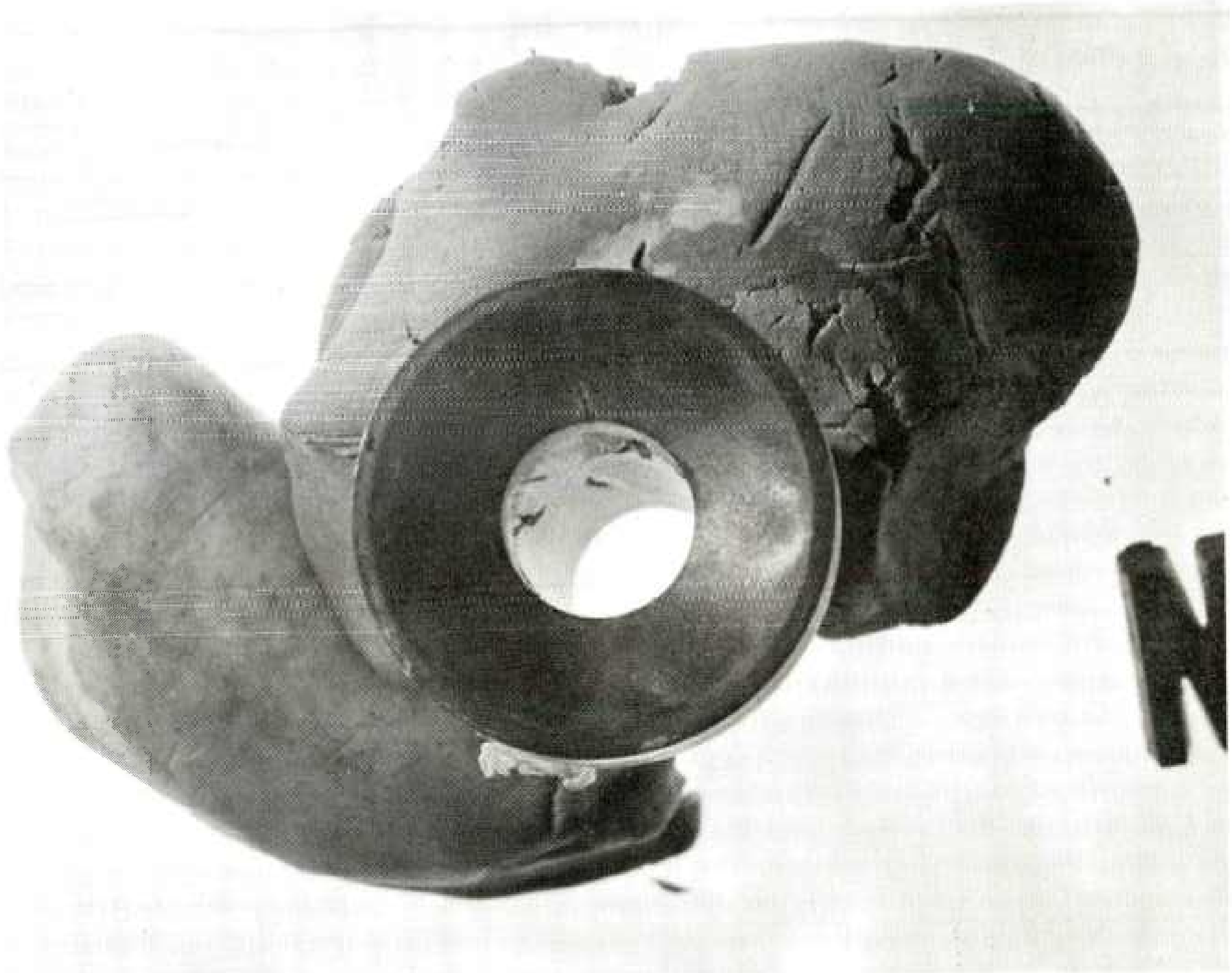

Figure 14. Graphite/Teflon/nylon agate displaying pits, voids, and fissures in the agate ID surface.

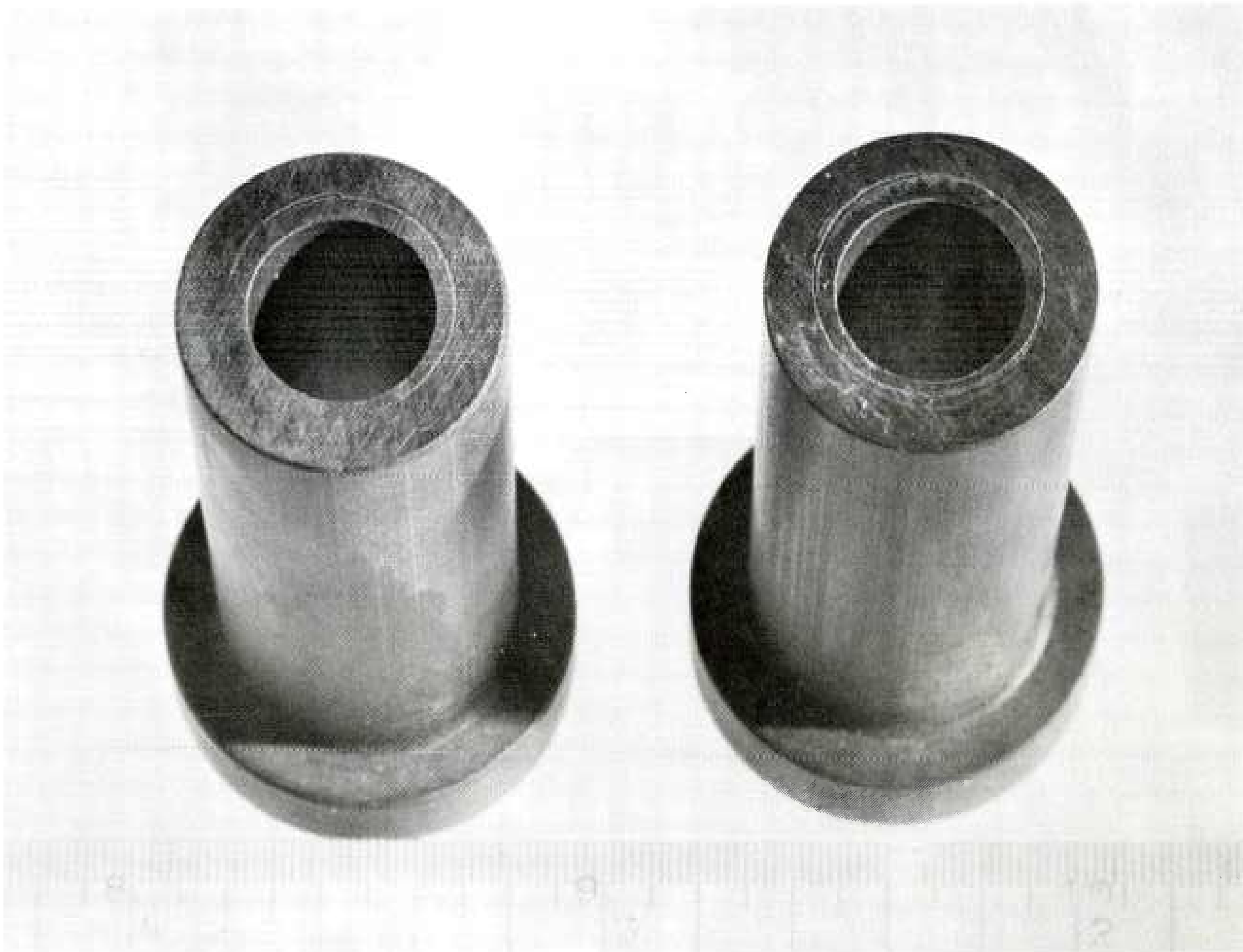

Figure 15. Typical graphite/Teflon/nylon agates displaying angular cuts (rings) in the exit web surface caused by the die agate removal tool.

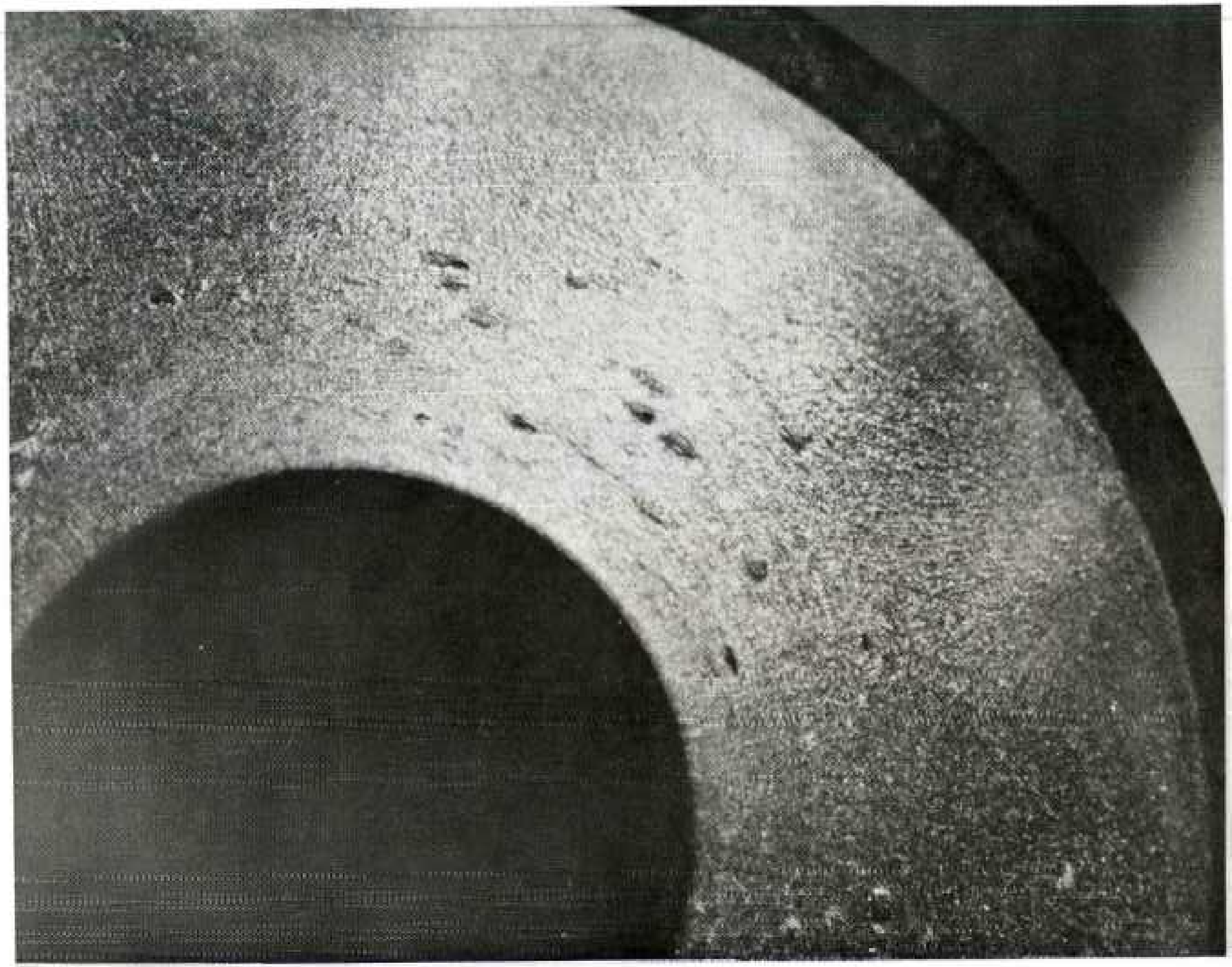

Figure 16. Typical example of the graphite/Teflon/nylon agates displaying porosity in the approach angle surface.
(This is an enlarged view of the top agate shown in Figure 13.)

(Figure 13). Figure 17 is an enlargement of the agate approach angle surface of No. 311 showing pits, voids, and evidence of delamination or poor material consolidation. Figure 18 shows several agates which have chips or dents in approach angle or exit surfaces that are presumed to occur during the die agate assembly, disassembly, or cleaning operations. A complete summary of the data obtained from this final inspection is included in Table 13. A review of these data led to the conclusion that this material has poor wear resistance and may even be chemically affected by cleaning solvents or propellant constituents, thus making it an unsatisfactory candidate for a die agate material.

Inspection of the graphite/Teflon/PPS agates, following the second week of usage, revealed faintly visible circumferential rings in the agate ID surfaces of agates Nos. 202 and 214. No. 204 also displayed the same type of circumferential rings in the agate ID after the fourth week of production usage. The standard measurement technique for measuring the ID dimension did not detect this anomaly, and the defect was not considered severe enough to warrant removal of the agates from the study. This condition was noted, however, since it was an indication of irregular material erosion in the agate ID surface and should be given consideration in any decision involving future use of die agates of this type of material.

Inspection of the graphite/Teflon/PPS agates following the fifth week of usage revealed that dimensionally all agates were acceptable although some damage from processing and/or usage was observed as follows:

a. Eight agates contained small chips or gouged places in the flat exit surface (web) of the agate. It was assumed that the damage was caused by the production die agate disassembly operation or by cuts in the agate ID exit area. The latter was presumed to be caused by the strand removal tool utilized to remove plugged strands from the agates while the die agates were still in the 305 mm (12 in) press. These agates involved were Nos. 203, 204, 205, 207, 211, 221, 222, and 225.

b. Two agates, Nos. 214 and 215, still displayed the fine lines or circumferential rings in the agate ID surface that had been observed following the second week of use. No additional wear was indicated.

c. One agate, No. 218, contained small pits in the approach angle surface of the agate.

None of the above defects were judged to be severe enough to warrant removal of any of the agates from the production evaluation cycle. All were released for further usage.

As a result of a production schedule change to minimize the impact of holiday downtime, it was decided to forego a shutdown for the normal six-week check, to monitor the three types of agates remaining under evaluation on-line, and to inspect them only if a defect was observed. At the end of the sixth week of evaluation, the supervisors of the operating

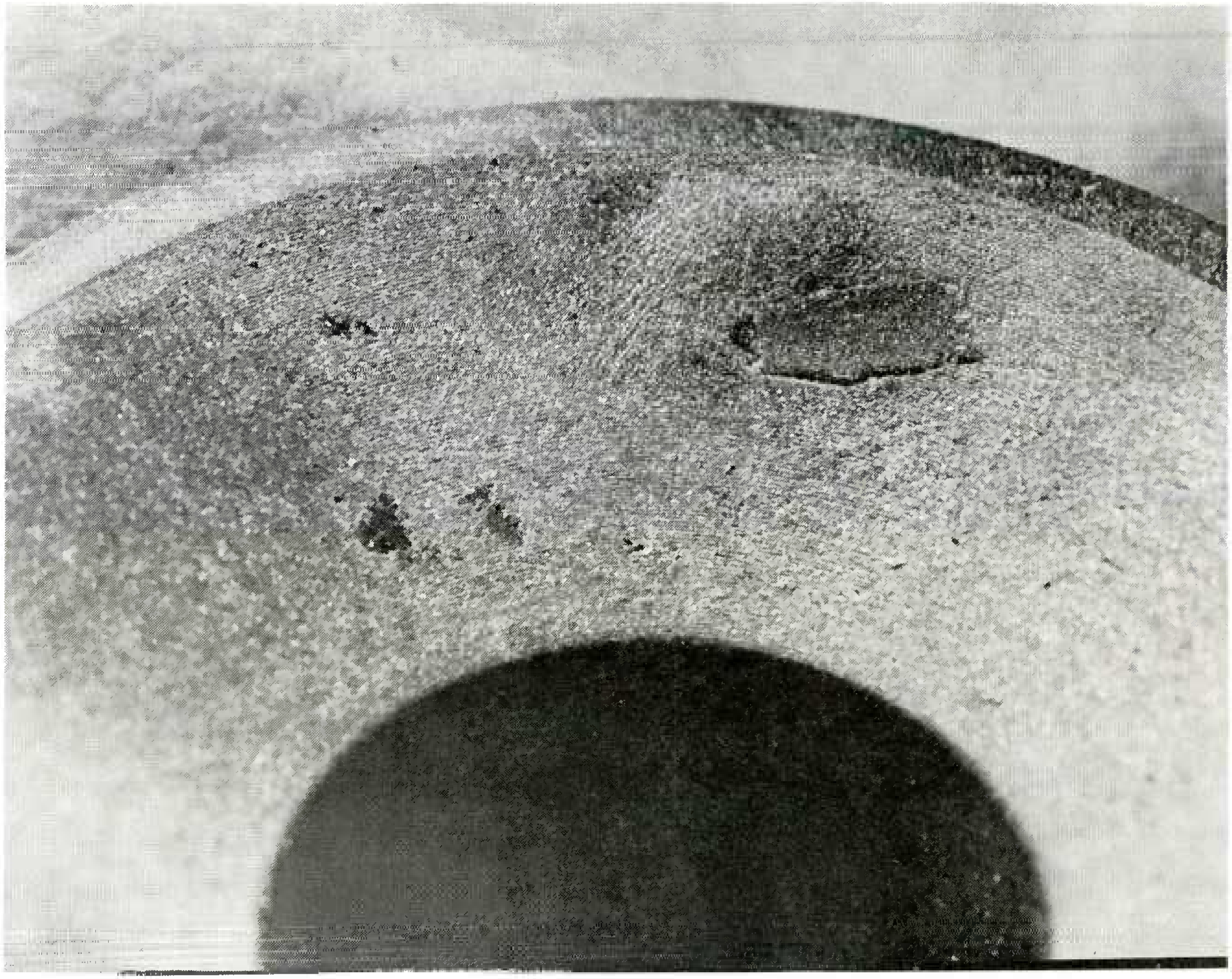

Figure 17. Typical graphite/Teflon/nylon agate showing both pits and voids in the approach angle and a large area resembling delamination of the molded composite material.

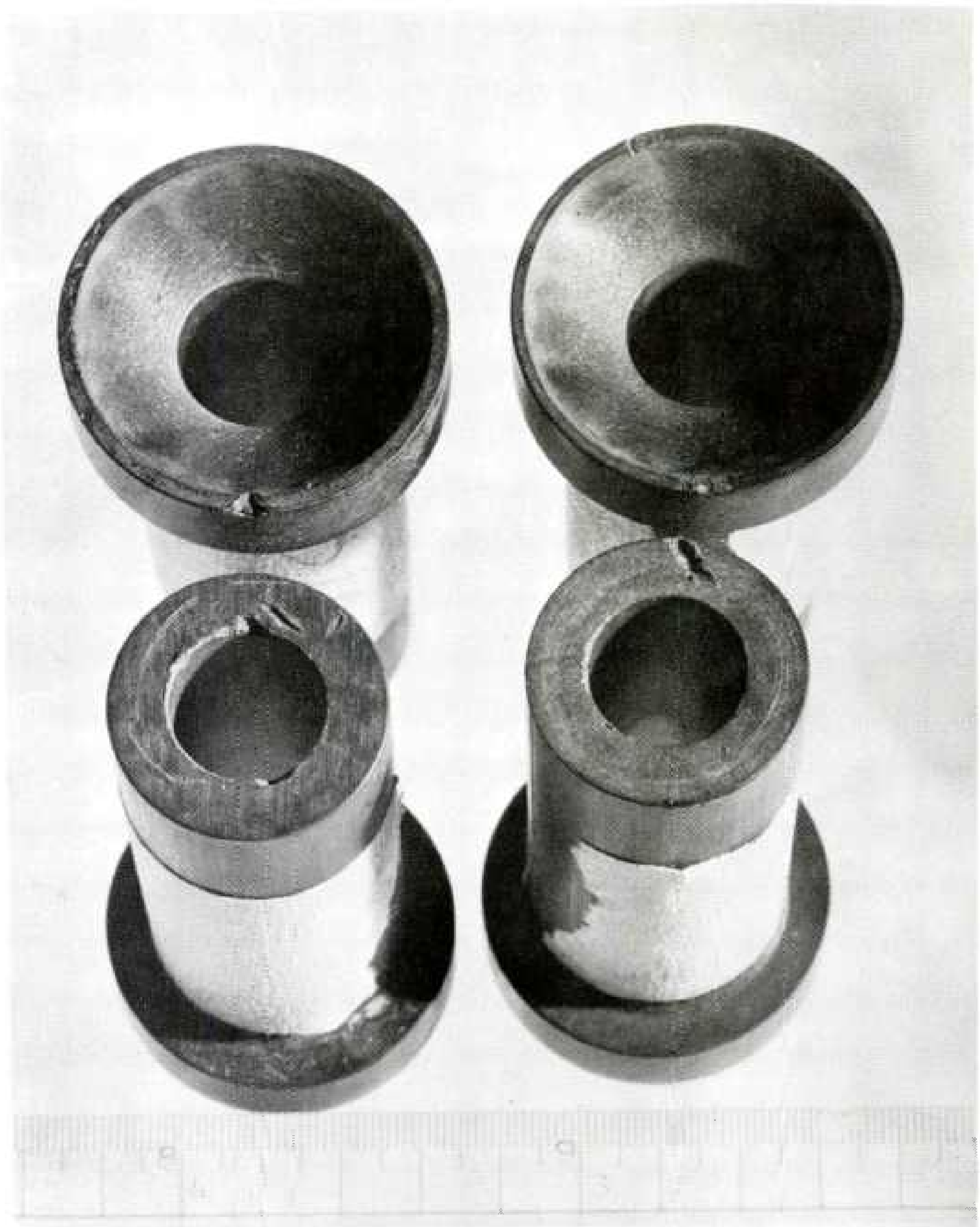

Figure 18. Typical graphite/Teflon/nylon agates with chips and dents in the approach angle and exit surfaces caused by production operations.

TABLE 13. SUMMARY OF FINAL INSPECTION DATA FOR GRAPHITE/TEFLON/NYLON DIE AGATES (End of Week 5)

Die No.	Agate Diameter: Approach mm	Approach in.	Middle mm	Middle in.	Exit mm	Exit in.	Remarks
301	8.811	0.3469	8.819	0.3472	8.816	0.3471	Small chips in approach angle; 1/4 of
	8.885	0.3498	8.842	0.3481	8.832	0.3477	circum shows weak
302	8.827	0.3475	8.804	0.3466			
	8.763	0.3450	8.865	0.3490	8.860	0.3488	
303	8.821	0.3473	8.824	0.3474			Pits in approach angle. Worn streak
	8.900	0.3504	8.862	0.3489	8.834	0.3478	(scratch) and pits in ID surface
304	8.809	0.3468	8.816	0.3471			Pits in approach angle. Three voids in ID
	8.898	0.3503	8.870	0.3492	8.824	0.3474	
305	8.814	0.3470			8.827	0.3475	Worn spot in ID. Two small voids in
	8.872	0.3493	8.824	0.3474	8.834	0.3478	approach surface
306	8.824	0.3474	8.821	0.3473	8.827	0.3475	Pits in approach. Worn and slightly
	8.865	0.3490	8.870	0.3492	8.837	0.3479	corrugated in ID area
307	8.816	0.3471	8.816	0.3471	8.834	0.3478	Pits in approach. Word ID 1/2 i . by 1/3
	8.875	0.3494	8.844	0.3482	8.842	0.3481	of circum
308	8.827	0.3475	8.827	0.3475			Pitted and worn, 3 in. by full circum.
	8.854	0.3486	8.849	0.3484	8.839	0.3480	Shiny area one in. by 1/6 of circum
309	8.814	0.3470	8.821	0.3473			Roughness or pits for 3/4 of length.
	8.862	0.3489	8.844	0.3482	8.814	0.3470	Mid ID, two small fissures with shiny spots
310	--	--	--	--	--	--	Removed week 4; fissure in ID
311	8.832	0.3477			8.824	0.3474	General pits in ID for approx 1/2 in. In
	8.870	0.3492	8.837	0.3479	8.834	0.3478	the approach, three small pits 1/32 x 1/16 in.
312	8.839	0.3480	8.829	0.3476	8.827	0.3475	Approach: three small pits. 1/32 x 1/16 in.
	8.895	0.3502	8.849	0.3484	8.832	0.3477	pitted 1/2 down by 1/3 of circum; ID
							gouged 1/32 by 3/8 in. long
313	8.819	0.3472	8.816	0.3471	8.816	0.3471	ID: shiny 3/4 in. down by 1/3 of circum
	8.890	0.3500	8.865	0.3490	8.827	0.3473	Approach: worn clover leaves - concave
							surface
314	8.827	0.3475	8.821	0.3473	8.824	0.3474	
	8.893	0.3501	8.837	0.3479	8.832	0.3477	
315	8.799	0.3464	8.806	0.3467	8.806	0.3467	Approach: several small pits. ID: fissure
	8.854	0.3486	8.829	0.3476	8.814	0.3470	1/2 in. long by 0.010 to 0.015 in. wide
316	8.801	0.3465	8.806	0.3467	8.799	0.3464	Top 1/2 in. shiny. Battered exit web
	8.890	0.3500	8.814	0.3470	8.804	0.3466	

TABLE 13. (Continued)

Die	Agate Diameter						
	Approach		Middle		Exit		
No.	mm	in.	mm	in.	mm	in.	Remarks
317	8.819	0.3472	8.827	0.3475	8.829	0.3476	Approach: worn concaved pits, small chips
	8.893	0.3501	8.854	0.3486	8.847	0.3483	at top
318	8.806	0.3467	8.816	0.3471	8.819	0.3472	ID: shiny spot 1/3 of circum, 3/4 in. long
	8.887	0.3499	8.844	0.3482	8.844	0.3482	
319	8.804	0.3466	8.814	0.3470	8.811	0.3469	ID: shiny spot 1/3 of circum, one in. long
	8.899	0.3499	8.849	0.3484	8.827	0.3475	
320	8.768	0.3452	8.819	0.3472	8.829	0.3476	Approach; slight concave wear
	8.809	0.3468	8.860	0.3488	8.839	0.3480	
321	8.821	0.3473	8.827	0.3475	8.816	0.3471	
	8.870	0.3492	8.839	0.3480	8.821	0.3473	
322	8.816	0.3471	8.819	0.3472	8.799	0.3464	ID: midway, several fissures
	8.839	0.3480	8.827	0.3475	8.821	0.3473	Approach: small pits similar to ID
323	8.811	0.3469	8.816	0.3471	8.821	0.3473	Streak of pits and voids; ID - shiny area
	8.763	0.3450	8.860	0.3488	8.834	0.3478	1/3 of circum by one in. long
324	8.827	0.3475	8.819	0.3472	8.816	0.3471	ID: worn streak 3/4 in. Pits and voids
	8.882	0.3497	8.832	0.3477	8.829	0.3476	Approach: concave wear
325	8.801	0.3465	8.816	0.3471	8.816	0.3471	ID: small fissure one in. long
	8.908	0.3507	8.882	0.3497	8.819	0.3472	Pits in approach surface
326	8.819	0.3472	8.824	0.3474	8.821	0.3473	Approach: small nicks. ID: streak of pits
	8.885	0.3498	8.852	0.3485	8.827	0.3475	Pinched area on OD
327	8.814	0.3470	8.816	0.3471	8.816	0.3471	Small pits on approach. Small pits on ID
	8.880	0.3496	8.837	0.3479	8.829	0.3476	1/2 in. down
328	8.816	0.3471	8.804	0.3466	8.804	0.3466	ID: exit web badly chipped. Approach:
		0.3483	8.834	0.3478	8.821	0.3473	slight concaveness and pits
329	8.814	0.3470	8.816	0.3471	8.809	0.3467	ID: small spiral fissure
	8.870	0.3492	8.877	0.3495	8.819	0.3472	Approach: small chip at top
330	8.880	0.3466	8.793	0.3462	8.814	0.3470	ID: gouged exit web, multiple small fissures
	8.880	0.3496	8.839	0.3480	8.821	0.3473	Approach: small pits, slightly concave
$\overline{X}$	8.87984	0.3496	8.83412	0.3478	8.82396	0.3474	
R	0.1397	0.0055	0.0889	0.0035	0.0406	0.0016	

department removed the graphite/Teflon/PPS agates because a number of the propellant strands being extruded contained rough surfaces which were suspected to be the result of some type of agate ID surface breakup. This condition was reported to the initiating engineer after the agates were removed from the die holders and the agates were given a preliminary visual inspection at the die cleaning and assembly building. A total of five agates were observed to have the webs at the exit surface chipped, gouged, or broken [up to 4.763 mm (0.1875 in) in depth, by half the circumference of the agate web surface] (see Figure 19 which depicts agates with this defect). Even those agates that did not display the web breakage generally had a fine circular indentation around the circumference of the web which tended to coincide with the chipped web surfaces. Figure 20 displays examples of the agates with chipped webs as well as the circular rings that tend to compare with the damaged webs as shown in Figure 19. A careful review was made of the die agate disassembly, cleaning, and reassembly operations in an attempt to identify the cause of these circular rings. The observation that the damage to exit web surface of the agate coincided with the circumferential rings found on the majority of the agates, whether badly chipped or not, led to the conclusion that some type of routine mechanical action on the agates had likely created sufficient stress on the agate surface to contribute to the breakage of the webs of the five agates in question. Further observation showed that the circular rings coincided with the roughened concave face of a brass rod routinely used as a tool in an arbor press by the operating personnel to remove the agates from the die holder prior to cleaning. It was concluded that after some time this pressing action had cut and/or weakened the physical integrity of the outer aft surface (web) of the agates, thus contributing to the breakage of the agate web surface. Since five of the 30 agates were damaged sufficiently to warrant removal from production and others contained the circular tool marks which could cause them to break upon reassembly, a decision was made to close out the evaluation at the completion of the sixth week of usage and to submit the agates to final inspection (as was done for the graphite/Teflon/PPS die agates). A complete summary of these final inspection results is presented in Table 14.

Three significant visual defects were highlighted as a result of the final inspection which are displayed in Figures 21 through 23. Figure 21 shows evidence of slight nicks in the outer edge of the agate approach angle and is presumed to be caused by some type of process mechanical action. Figure 22 depicts the irregular wear (annular rings) shown in the ID of the agate and was present and essentially unchanged since the second week of use. Figure 23 is an enlarged view of pits and voids observed in several agate approach angle surfaces of which agate No. 218 was judged to be the most excessive. This condition did not tend to contribute to irregular wear and was not judged to be as significant as the pitting and erosion as observed in the graphite/Teflon/nylon agates.

Figure 24 shows typical examples of graphite/Teflon/PPS agates judged to be free of significant defect after six weeks of production usage. They may be visually compared for a comparison of serviceability to the agates shown in Figure 6.

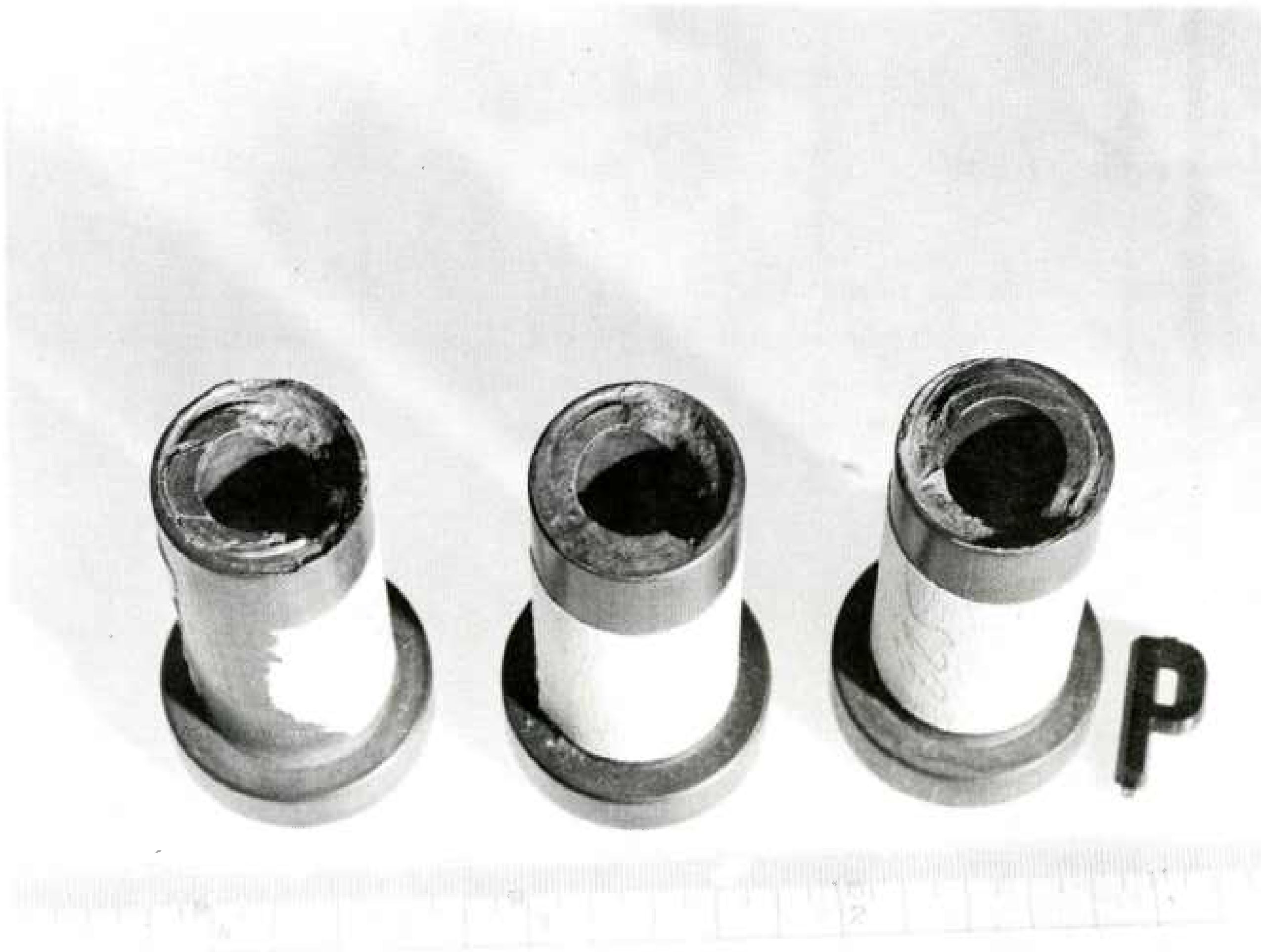

Figure 19. Examples of graphite/Teflon/PPS agates showing damage to exit web surfaces.

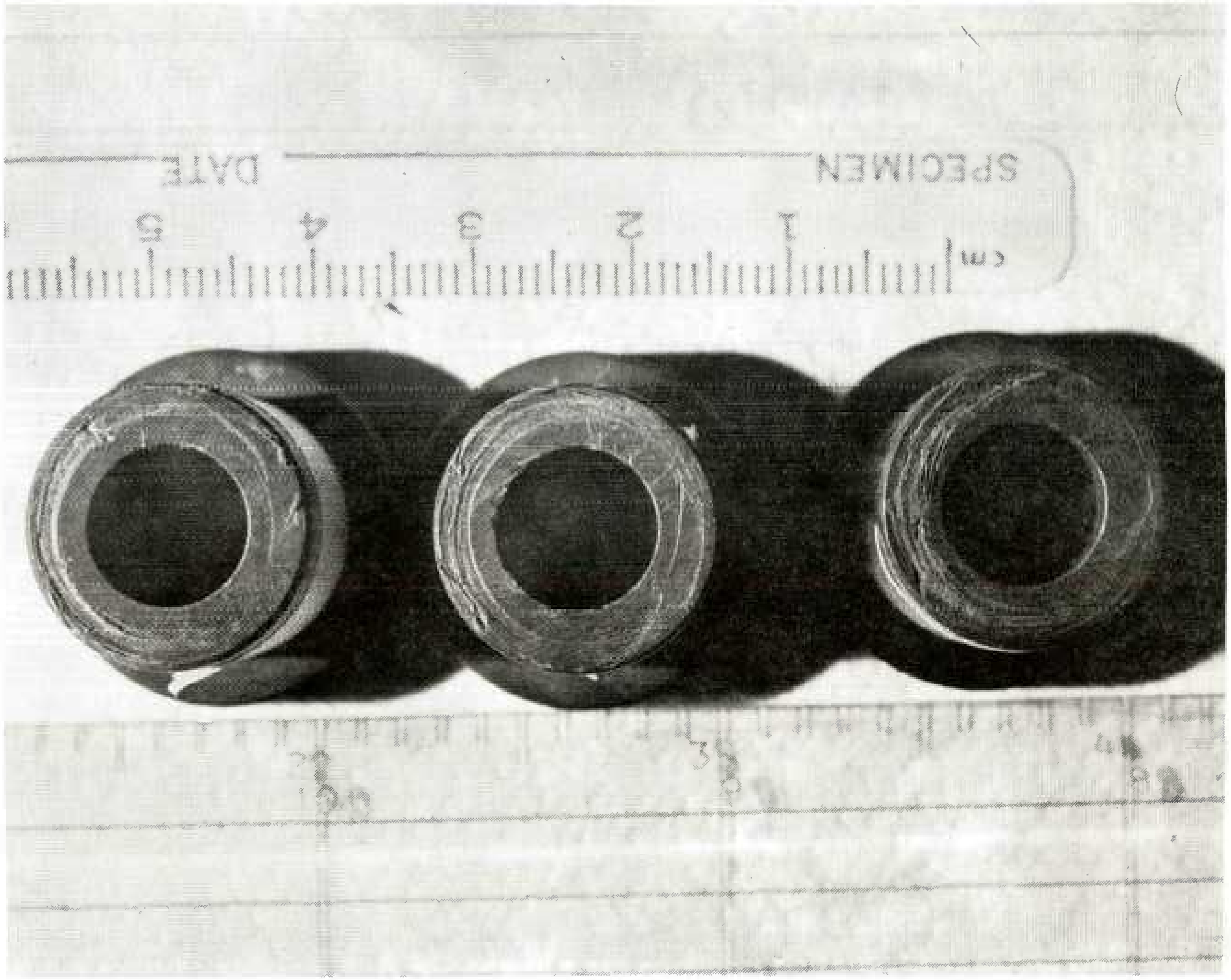

Figure 20. Examples of graphite/Teflon/PPS agates showing angular rings caused by the die removal tool and related to web damage depicted in Figure 19.

TABLE 14. SUMMARY OF FINAL INSPECTION DATA FOR GRAPHITE/TEFLON/PPS DIE AGATES (End of Week 6)

Die	Agate Diameter						
	Approach		Middle		Exit		
No.	mm	in.	mm	in.	mm	in.	Remarks
201	8.857	0.3487	8.854	0.3486	8.865	0.3490	Web at exit end broken 1/2 of circum to a depth inward to ID 3/16 in. deep. Small chip top edge of approach
202	8.860	0.3488	8.862	0.3489	8.875	0.3494	Pits in approach angle. ID worn in a wash board
203	8.862	0.3489	8.854	0.3486	8.862	0.3489	Damaged web at exit end of die. Pits in approach angle. Several gouged places with a max depth of 3/16 in.
204	8.860	0.3488	8.872	0.3493	8.877	0.3495	Small pits in approach angle. Slight burr in exit ID.
205	8.852	0.3485	8.860	0.3488	8.857	0.3487	Small pits in approach angle. Circles formed by die removal tool in exit web face
206	8.857	0.3487	8.857	0.3487	8.860	0.3488	Circles formed by die removal tool in exit web face
207	8.870	0.3492	8.862	0.3489	8.862	0.3489	Web at exit end broken 1/2 of the circum to a depth inward to ID 3/16 in. deep
208	8.857	0.3487	8.865	0.3490	8.867	0.3491	Web at exit end broken 1/3 of the circum to a depth inward to ID 1/8 in. deep
209	8.867	0.3491	8.865	0.3490	8.860	0.3488	Slight tool marks on exit web face
210	8.862	0.3489	8.862	0.3489	8.865	0.3490	
211	8.865	0.3490	8.862	0.3489	8.860	0.3488	Two small chips on top edge of approach angle
212	8.865	0.3490	8.865	0.3490	8.862	0.3489	
213	8.865	0.3490	8.865	0.3490	8.862	0.3489	
214	8.870	0.3492	8.867	0.3491	8.870	0.3492	Small ridges in ID. Faint circum rings
215	8.854	0.3486	8.852	0.3485	8.852	0.3485	
216	8.854	0.3486	8.857	0.3487	8.857	0.3487	Small chip in top edge of approach. Small chip in web at exit end extending to ID
217	8.854	0.3486	8.862	0.3489	8.865	0.3490	
218	8.844	0.3482	8.852	0.3485	8.847	0.3483	Small pits in approach angle
219	8.852	0.3485	8.852	0.3485	8.862	0.3489	Small angular ring on aft web surface
220	8.849	0.3484	8.852	0.3485	8.860	0.3488	Small pits in approach angle

TABLE 14. (Continued)

Die No.	Agate Diameter: Approach mm	Approach in.	Middle mm	Middle in.	Exit mm	Exit in.	Remarks
221	8.860	0.3488	8.860	0.3488	8.854	0.3486	
222	8.844	0.3482	8.847	0.3483	8.842	0.3481	Small pits in approach angle. Small chip in web to ID
223	8.849	0.3484	8.847	0.3483	8.852	0.3485	
224	8.862	0.3489	8.857	0.3487	8.857	0.3487	Web at exit end broken 1/3 of circum to a depth of 3/16 in. inward to ID. Rough groove in ID 3/4 in. long by 0.030 in. wide (tool scar)
225	8.857	0.3487	8.860	0.3488	8.860	0.3488	Web at exit end broken 1/2 of circum to a depth of 3/16 in. inward to ID
226	8.867	0.3491	8.872	0.3493	8.872	0.3493	Small pits in approach angle
227	8.849	0.3484	8.847	0.3483	8.852	0.3485	
228	8.860	0.3488	8.854	0.3486	8.852	0.3485	
229	8.920	9.3512	8.887	0.3499	8.885	0.3498	Small pits in approach angle
230	8.857	0.3487	8.854	0.3486	8.852	0.3485	Two small chips in top edge of approach
$\overline{X}$	8.8595	0.34880	8.8593	0.34879	8.8608	0.34885	
R	0.0762	0.0030	0.0406	0.0016	0.0432	0.0017	

NOTE: In general, all dies have tool marks caused by the die agate removal process, whether highlighted by individual inspection remarks or not. Some are more pronounced than others and tend to coincide with the badly chipped exit web surfaces as noted.

Figure 21. Examples of graphite/Teflon/PPS agates with chips in the outer edge of the approach angle.

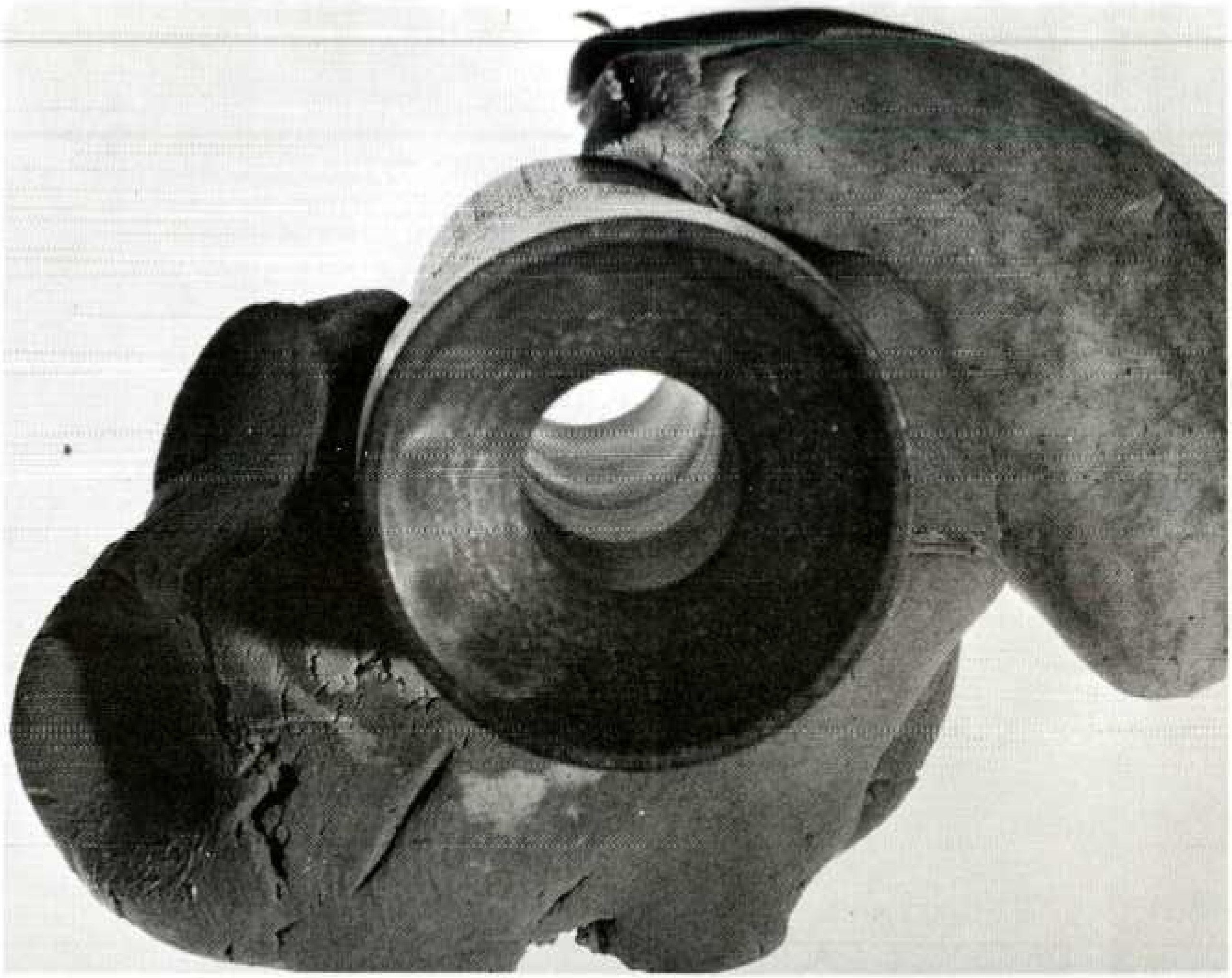

Figure 22. Example of graphite/Teflon/PPS agate showing angular rings indicating irregular agate ID wear.

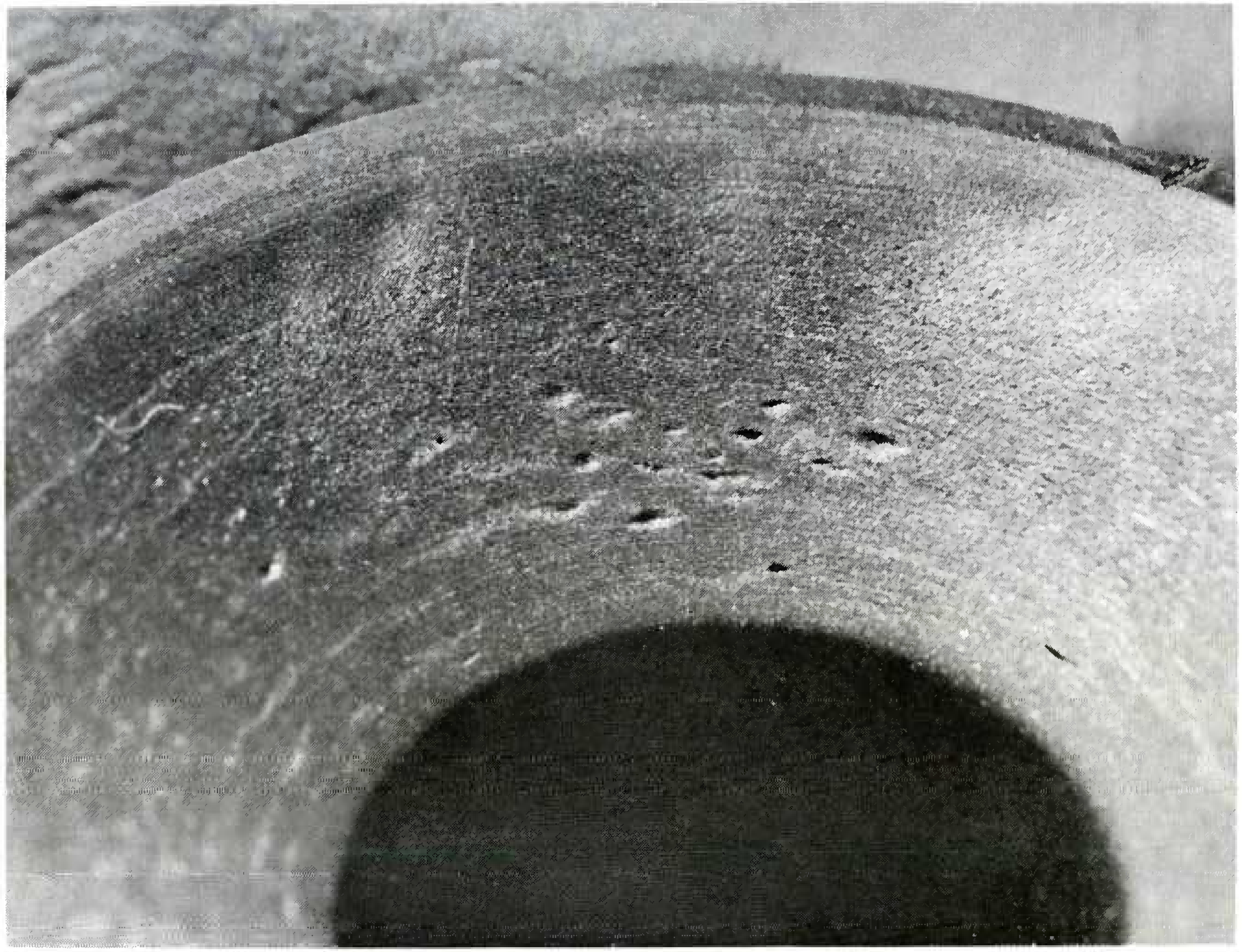

Figure 23. An enlargement of the approach angle surface of a graphite/Teflon/PPS agate which shows pitting that occurred in several agates.

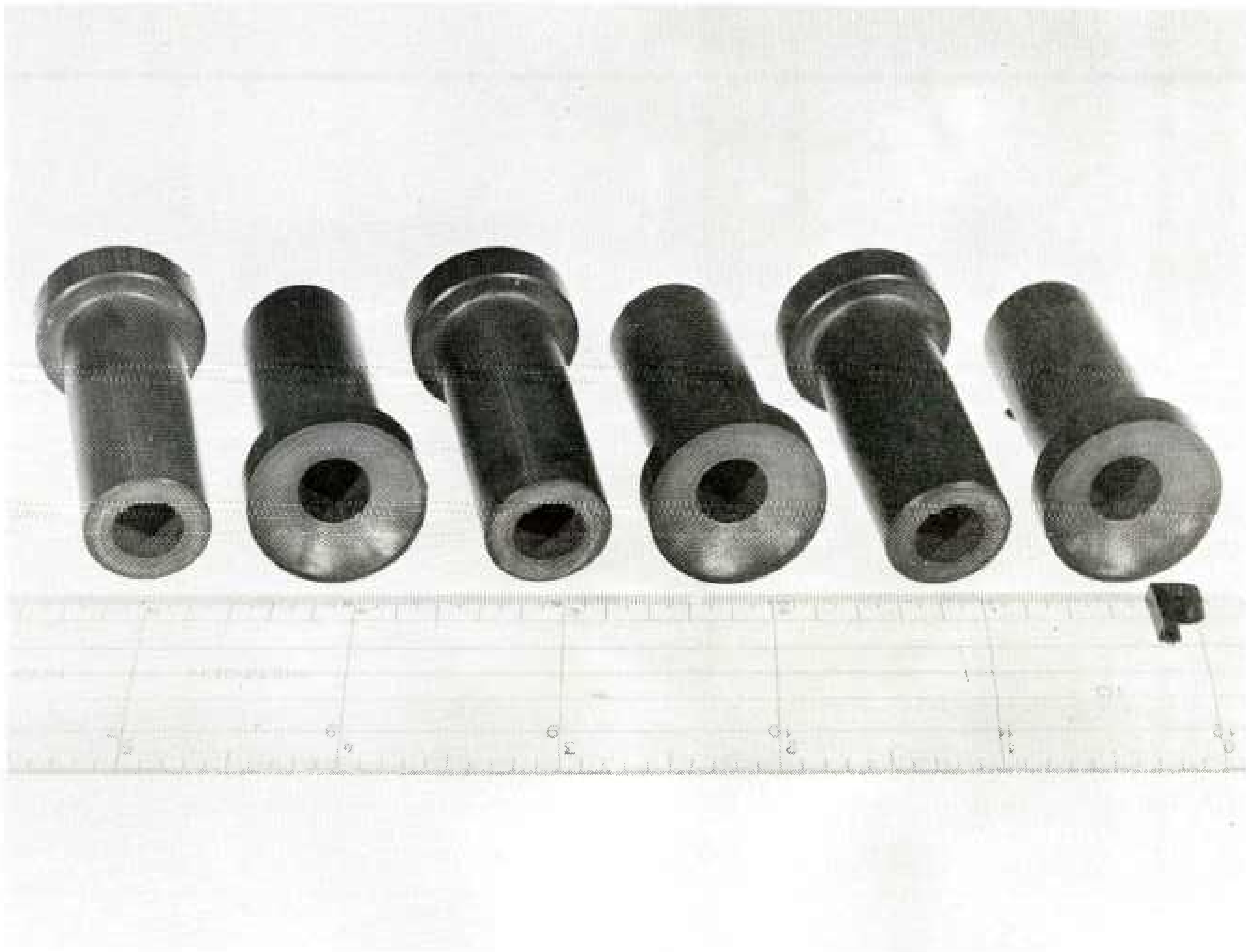

Figure 24. Examples of graphite/Teflon/PPS agates at the completion of the six week evaluation period.

IV. ECONOMIC ANALYSIS

A. Basis of Analysis

The evaluation of agates during this study was performed on 105-mm M490 propellant which is granulated in 305-mm (12 in) diameter solvent presses. Approximately 1.82 Mg (four million lb) of this propellant item was produced in CY-1977, and 1.95 Mg (4.3 million lb) is presently programmed for production in CY-1978. Generally, to support this level of production, one complete press house consisting of eight operating 305-mm (12 in) diameter presses is set up at one time, approximately every two months, and operated continuously (normally on a 3-8-5 shift basis) until sufficient propellant has been granulated to support the planned packout schedule. This level, however, is that capable of producing 0.456 Mg (one million lb) of this type of propellant per month and is the level chosen for use in the economic analysis. Each of the eight operating presses requires five die holders, which utilize five agates each, or 25 agates per press. In addition, sufficient spare die holders are assembled so that any time a press is shut down for any significant length of time for replacement of individual agates (caused by damage, maintenance work on equipment, or disrupted propellant process flow), the agates can be removed and freshly cleaned ones installed prior to starting the press again. This generally equates to the use of one extra die holder (five agates) per operating press as spares.

The investigative work performed during this study showed that when the Delrin agates were utilized for the production of triple-base propellant, approximately 80 percent failed the agate ID dimensions (after each week of production) due to absorption of NG by Delrin. Generally, this required the removal from the line periodically and reaming of the ID. This means that to be assured of this minimum number of agates, the inventory of agates with acceptable dimensions must be significantly increased.

Therefore, it can be readily determined that to properly equip one complete press house with Delrin agates requires as a minimum 528 agates. This includes:

On Line	240
Die Cleaning Awaiting Stabilization	192
In Shop for Dimension Rework (Approximately 50% of last set taken out of production)	96
Total	528

Because of the overall stability of the graphite/Teflon/PPS agates, only 240 agates are estimated to be required to fully equip the same size press house. From the wear analysis obtained from the use of the graphite/Teflon/PPS agates, discounting any loss caused by excessive production

handling damage, the graphite/Teflon/PPS agates will last at least four times longer than Delrin.

No economic analysis is being provided for the graphite/Teflon/nylon agates. This type of agate was judged not to be acceptable for use in the manufacture of triple-base propellants because of its lack of dimensional stability, poor wear characteristics, and tendency to form pin holes and fissures during usage.

The economics of using Teflon-coated steel agates was examined should it prove to be advisable to utilize this agate type under certain selected processing conditions. This agate appeared to offer the greatest degree of wear resistance of any studied; however, it is not feasible to utilize on any new propellant die configuration or use on dies for production of propellants with short production runs because of the elapsed time required for an off-plant vendor to apply the coating. Following the repair of any production damage or minor dimensional changes necessitated by process changes, the agates will require recoating at a vendor plant. For this reason, agates using this coating technique are not feasible for use in a production plant without the capability to apply coating rapidly to support changes in production operations and commitments. If, however, a decision is made to utilize this agate type, an effort should be made to acquire the proprietary Nedox process so that the coating can be applied at RAAP.

B. Comparison of Economic Factors

To determine the potential cost savings that can be derived from the use of the graphite/PPS or the Teflon-coated steel die agates, the following economic analyses were made.

1. Current Method--Delrin Agate Inserts

Inserts Required per 0.456 Mg (10^6 Pounds) Propellant	240
Inserts Required per 0.456 Mg (10^6 Pounds) Propellant - Maintenance and Rework	288
Cost/Insert (each)	\$30.78
Total First Year Cost:	528 x \$30.78 = \$16,252
Annual Replacement Cost (100%):	528 x \$30.78 = \$16,252

2. Proposed Method--Graphite/Teflon/PPS

a. Assumptions

(1) Cost of Agate (RAAP)

Manufacturing Labor and Overhead (RAAP)	$11.02
Graphite/Teflon/PPS Agate Blanks (Purchased)	1.95*
*Units of 500 to 1450 Blanks	
	$12.97

(2) Estimated Number of Agates Required

Agates Required per 0.456 Mg (10^6 Pounds) Propellant	240
Agates Required per Year for Maintenance and Replacements (25%)	60

(3) Cost of Agates

Cost to Equip and Maintain One Press House for First Year: 240 x $12.97 =	$3,113
Annual Replacement Cost: 60 x $12.97 =	$ 778

3. Alternate Proposed Method--Teflon-Coated Steel

a. Assumptions

(1) Cost of Agate (RAAP)

Manufacturing Labor and Overhead	$24.80
Steel Required	0.50
Nedox Coating (Sub-Contractor)	3.20
Total Cost per Agate	$28.50

(2) Recurring Costs (Annually)

Decontaminating*	$ 2.00
Inspecting (Before and After Coating)	4.00
Coating - Nedox (Sub-Contractor)	3.00
Replacements @ 25%	6.33
Total Cost per Agate on a Recurring Basis	$15.53

*ROM estimate of conventional heat decontamination procedures. No process has been established yet to assure doing this without damaging agates.

(3) Estimated Number of Agates Required

Teflon/Steel Agates Required per 0.456 Mg (10^6 Pounds) Propellant	240
Teflon/Steel Agates Required per 0.456 Mg (10^6 Pounds) Propellant to Assure Adequate Spares (50% backup)	120
Total Needed	360

b. Cost of Agates

Cost to Equip and Maintain One Press House: 360 x $28.50 =	$10,260
Annual Replacement Costs: 360 x $15.53 =	$ 5,590

4. Cost to Make the Change — 0

(This assumes that there is no obsolescence with Delrin agates since the material has no value and should not be used. The steel jackets can be cycled through other agate types until used up.)

5. Savings First Year

Graphite/Teflon/PPS	($16,252 - $3,113)	$13,139
Teflon-Coated Steel	($16,252 - $10,260)	$ 5,992

6. Savings/Year after First Year

Graphite/Teflon/PPS	($16,252 - $778)	$15,474
Teflon-Coated Steel	($16,252 - $5,590)	$10,662

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The main conclusions from the quantitative elements of this study are:

1. Teflon-coated steel and graphite/Teflon/PPS dies do not change* dimensionally with use.

2. Graphite/Teflon/nylon and Delrin dies change* dimensionally with use.

*99 percent significance level.

3. The expected life of Delrin and graphite/nylon dies is less than that of Teflon-coated steel or graphite/PPS by at least a factor of four.

4. Propellant dimensions are not significantly affected by die type.

5. Ballistic performance (RQ) is not significantly affected by die type.

6. Analytical results show Delrin absorbs NG and, in time, could preclude reworking because of the hazards involved.

7. Shrinkage data for graphite composition dies shows that die agates cannot be molded to meet all dimensional measurements, but the majority of dimensions can be met, thus minimizing final machining costs.

Conclusions drawn from observations are:

1. All three nonsteel dies (i.e., Delrin and the two graphite composition types) are easily damaged using normal die cleaning and handling procedures.

2. Teflon-coated steel showed two tendencies that need further observations over a longer period of production use to fully evaluate significance of import as follows:

a. Slight buildup of Teflon coating (restricted ID) at the inner edges of barrel web at the ID surface indicating that the Teflon may be flowing slightly under use.

b. Visual appearance of slight breakdown (i.e., "honeycombing" appearance in the center of the agate barrel ID surfaces), presumed to be a partial disintegration of the Teflon coating. This may contribute to the apparent Teflon coating flowing as noted above.

3. Graphite/Teflon/nylon composition agates showed excessive erosion of the ID near the approach angle, as well as pinholing early in the production run. These defects gradually worsened until a high majority of agates had excessive ovality and displayed pinholes or fissures in the ID surfaces, thus causing them to be unusable.

B. Recommendations

Based on the results of this study, the following recommendations are made:

1. That either graphite/Teflon/PPS or Teflon-coated steel be used as a replacement for Delrin. The replacement program should be sequenced to

provide additional information relative to serviceable life in high production usage. If proven completely satisfactory, then other propellant dies could be phased out and replaced with one of these types.

2. That the current system for handling and cleaning of dies be investigated for improvements in operational techniques to preclude damage to nonsteel dies.

3. If graphite/Teflon/PPS is selected, the replacements should be compression-molded die agate blanks as evaluated in this study; and, that RAAP work with the supplier to provide blanks closer to required dimensions, with final machining to be accomplished at RAAP. This approach reduces material and labor costs. It is further recommended that the Government-owned mold be retained at the vendor's plant pending a decision to buy agate blanks as is, or to further modify the mold to minimize shrinkage.

4. If Teflon-coated steel is selected, an investigation of steel dies be conducted prior to any purchases of replacements. In addition to the above, efforts should be made to acquire the process for Teflon coating of steel dies, if Teflon coating is found to be necessary for quality of propellant and longer wear of dies.

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